

**Strategic survey of sound levels in operating theatres and the ICU
at Christchurch Hospital and assessment of their effects on
personnel and patients**

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Abstract

Hospitals are intended to be quiet spaces to enhance tranquility and patient recovery. Studies conducted overseas suggest hospitals are excessively noisy in comparison with World Health Organization recommendations. This affects both patients and staff in terms of recovery time and exposure to occupational noise respectively. This study determined noise levels and sources in the intensive care units over both day and night periods. Occupational noise may also affect the hearing and concentration levels of staff, therefore noise levels were also measured in orthopaedic and cardiac surgery units and compared with International Standards Organization guidelines. Surveys were also completed to determine subjective impacts of noise. The aim of this study was to assess where the noise levels in Christchurch Hospital were in relation to similar hospitals overseas, if ICU noise exceeded WHO (Berglund, et al, 1999) noise recommendations and if surgery noise breached the Health and Safety in Employment Regulations (Department of Labour, 1995).

Noise levels in the ICU had an L_{Aeq} of 55-60dB(A) during the day and 45-50dB(A) at night, with peaks elevated above 100dB(C), all exceeding WHO (Berglund, et al, 1999) recommended levels. Noise levels in surgeries showed L_{Aeq} levels between 60-75dB(A) and peak levels above 100dB(C), not breaching the Health and Safety in Employment Regulations (Department of Labour, 1995). Staff surveys indicated a negative attitude towards noise, with over half of participants stating they would feel better if their workplace was less noisy and reporting they sometimes cannot concentrate because of the level of noise.

Noise levels in the Christchurch Hospital should be reduced for patient tranquility and staff concentration.

Table of Contents

Acknowledgements.....	2
Abstract	3
Table of Contents	4
List of Abbreviations.....	7
List of Figures	8
List of Tables.....	10
 Chapter One: Introduction	 11
1.1 Overview	11
1.2 Noise pollution	12
1.3 Characteristics of sound	13
1.3.1 Sound pressure.....	13
1.3.2 Frequency	14
1.3.3 Pure-tone.....	16
1.3.4 Impulse noise	16
1.4 Noise measurement	17
1.4.1 Reverberation time	18
1.4.2 Attenuation.....	18
1.5 Noise and the patient.....	19
1.5.1 Recommended noise levels	19
1.5.2 Noise and sleep	20
1.5.3 Physiological and psychological effects	21
1.5.4 Hospital noise levels	23
1.5.5 Subjective opinion and questionnaires.....	26
1.6 Occupational noise	27
1.6.1 Recommended noise levels	27
1.6.2 Noise and cognition	28
1.6.3 Physiological effects	29
1.6.4 Hospital noise levels	30
1.6.5 Subjective opinion and questionnaires.....	32
1.6.6 Hearing loss.....	33
1.7 Noise in New Zealand hospitals	35
1.8 Noise reduction	36
1.9 Research aims and questions.....	39
 Chapter Two: Method	 40
2.1 Ethics approval.....	40
2.2 Participants	40
2.3 Procedure	40
2.3.1 ICU	40
2.3.2 Surgical unit.....	42
2.3.3 Staff and patient surveys	43

2.4 Data analysis	44
2.4.1 ICU data.....	44
2.4.2 Surgical data	45
2.4.3 Surveys	45
Chapter Three: Results	46
3.1 ICU	46
3.1.1 Room dimensions	46
3.1.2 Noise measurements	47
3.1.2.1 L_{Aeq}	48
3.1.2.2 L_{A10} , L_{A50} and L_{A90}	53
3.1.2.3 L_{AFmax} and L_{AFmin}	55
3.1.2.4 L_{Cpeak}	57
3.1.2.5 Number of peaks exceeding 75dB(A)	57
3.1.3 Spectral analysis	61
3.2 Surgical unit.....	63
3.2.1 Room dimensions and reverberation time	63
3.2.2 Noise measurements	66
3.3 Staff surveys.....	67
Chapter Four: Discussion	70
4.1 ICU	70
4.1.1 Reverberation and attenuation	70
4.1.2 Noise levels	70
4.1.2.1 L_{Aeq}	70
4.1.2.2 L_{AFmax} , L_{AFmin} , L_{A10} , L_{A50} and L_{A90}	71
4.1.2.3 Peaks	72
4.1.2.4 Spectral analysis	75
4.1.2.5 Extraneous factors	75
4.2 Surgical unit	78
4.2.1 Reverberation and attenuation	78
4.2.2 Noise levels	78
4.3 Staff surveys	80
4.4 Future considerations	81
4.4.1 ICU	81
4.4.2 Surgical unit.....	84
4.4.3 Staff surveys	84
4.4.4 Noise reduction.....	85
Chapter Five: Conclusions	87

References.....	89
Appendices.....	95
Appendix 1. Human Ethics Committee approval	95
Appendix 2. Preliminary sound level measurements	96
Appendix 3. Staff survey consent and information form.....	97
Appendix 4. Staff survey questionnaire.....	101
Appendix 5. Patient survey questionnaire and information form.....	103
Appendix 6. Fletcher-Munson equal loudness contours	106
Appendix 7. Busch-Vishniac rising noise levels	106
Appendix 8. Spectral data	107
Appendix 8a. Spectral analysis of Thursday morning, including a high number of peaks with microphone 1	107
Appendix 8b. Spectral analysis of noise levels on Thursday morning, including a high number of peaks with microphone 2.....	107
Appendix 8c. Spectral analysis of noise levels on Monday morning, including a high number of peaks with microphone 1	108
Appendix 8d. Spectral analysis of noise levels on Saturday night, including a high number of peaks, one at 135dB(C)with microphone 2.....	108
Appendix 8e. Spectral analysis of noise levels on Monday early morning, including a low number of peaks with microphone 1	109
Appendix 8f. Spectral analysis of noise levels on Monday night, including a low number of peaks with microphone 1	109
Appendix 8g. Spectral analysis of noise levels late Monday night, including a low number of peaks with microphone 1	110
Appendix 8h. Spectral analysis of noise levels on early Wednesday morning, including a low number of peaks with microphone 2.....	110
Appendix 9. Microphone placements in the ICU.....	111
Appendix 9a. Microphone one placement.....	111
Appendix 9b. Microphone cables running along the side of administration/nursing station.....	112
Appendix 9c. Microphone two cables	112
Appendix 9d. Microphone two placement above bed five.....	113

List of Abbreviations

ACC: Accident Compensation Corporation (New Zealand)

ANSI: American National Standards Institute

dB: Decibel

EPA: Environmental Protection Agency

Hz: Hertz

ISO: International Standards Organization

L_{A10}: The A-weighted noise level just exceeded for 10% of measurement time

L_{A50}: The A-weighted noise level just exceeded for 50% of measurement time

L_{A90}: The A-weighted noise level just exceeded for 90% of measurement time

L_{Aeq}: A-weighted equivalent continuous noise level

L_{AFmax}: Maximum A-weighted fast response sound level

L_{AFmin}: Minimum A-weighted fast response sound level

L_{Cpeak}: Peak C-weighted sound level

MRI: Magnetic resonance imaging

NIHL: Noise-induced hearing loss

NIOSH: National Institute for Occupational Safety and Health

PTS: Permanent threshold shift

RT60: Time taken for sound to decay by 60dB, referred to as reverberation time

TTS: Temporary threshold shift

SPL: Sound pressure level

WHO: World Health Organization

List of Figures

Figure 2.1. Christchurch Hospital ICU layout.

Figure 3.1. Christchurch Hospital ICU measurements.

Figure 3.2. L_{Aeq} as a function of time of day for Monday 21st September 2015.

Figure 3.3. L_{Aeq} as a function of time of day for Tuesday 22nd September 2015.

Figure 3.4. L_{Aeq} as a function of time of day for Wednesday 23rd September 2015.

Figure 3.5. L_{Aeq} as a function of time of day for Thursday 24th September 2015.

Figure 3.6. L_{Aeq} as a function of time of day for Friday 25th September 2015.

Figure 3.7. L_{Aeq} as a function of time of day for Saturday 26th September 2015.

Figure 3.8. L_{Aeq} as a function of time of day for Sunday 27th September 2015.

Figure 3.9. L_{A10} , L_{A50} and L_{A90} for the week of sound level measurement for microphone one.

Figure 3.10. L_{A10} , L_{A50} and L_{A90} for the week of sound level measurement for microphone two.

Figure 3.11. L_{AFmax} and L_{AFmin} for the week of sound level measurement with microphone one.

Figure 3.12. L_{AFmax} and L_{AFmin} for the week of sound level measurement with microphone two.

Figure 3.13. Maximum L_{Cpeak} values over times of day for the week of sound level measurement.

Figure 3.14. Number of peaks exceeding 75dB(A) for each time of day on Monday 21st September 2015.

Figure 3.15. Number of peaks exceeding 75dB(A) for each time of day on Tuesday 22nd September 2015.

Figure 3.16. Number of peaks exceeding 75dB(A) for each time of day on Wednesday 23rd September 2015.

Figure 3.17. Number of peaks exceeding 75dB(A) for each time of day on Thursday 24th September 2015.

Figure 3.18. Number of peaks exceeding 75dB(A) for each time of day on Friday 25th September 2015.

Figure 3.19. Number of peaks exceeding 75dB(A) for each time of day on Saturday 26th September 2015.

Figure 3.20. Number of peaks exceeding 75dB(A) for each time of day on Sunday 27th September 2015.

Figure 3.21. Spectral analysis of noise levels on Thursday morning, including a high number of peaks exceeding 75dB(A) from microphone two.

Figure 3.22. Spectral analysis of noise levels on Thursday early morning with few peaks exceeding 75dB(A) from microphone two.

Figure 3.23. Spectral analysis of noise levels on Saturday night with microphone two, including the highest peak recorded of 135dB(C).

Figure 3.24. Dimensions and layout of theatre four.

List of Tables

Table 1.1. Methods and results of noise measurement in ICUs worldwide and whether they meet WHO (Berglund, et al, 1999) guidelines.

Table 1.2. Equivalent noise level and its corresponding exposure time (Liddell, 2008).

Table 1.3. Methods and results of noise measurement in operating theatres and whether they meet Health and Safety in Employment Regulations (Department of Labour, 1995).

Table 3.1. Calculated reverberation times for theatre four.

Table 3.2. Two measurements of each type of surgery, their statistical parameters and notes on subjective noise levels/sources.

Table 3.3. Table of staff questionnaire variables and their frequency and percentages determined by descriptive statistics.

Chapter One: Introduction

1.1 Overview

Hospital noise levels worldwide are in excess of international guidelines (Berglund, et al, 1999) and can have negative effects on patients and staff alike. Previous studies show a rising trend in hospital noise levels over the last 50 years (Busch-Vishniac, 2005; Shahid, Bashir, Sabir & Awan, 2014), partly due to technological developments and staff communications. Hospital patients in typical intensive care units (ICUs) need a healthy, restorative environment in which to recover as they are particularly vulnerable to the effects of noise pollution (Goines & Hagler, 2007). Patient recovery is affected by many factors, one of which is noise exposure (Hsu, et al, 2010).

Noise pollution has been an ongoing issue throughout modern times, with previous research reiterating Florence Nightingale's 1859 quote: "Unnecessary noise, then, is the most cruel absence of care, which can be inflicted on either sick or well," (Busch-Vishniac, et al, 2005). The World Health Organization (WHO) regard noise as the leading stressor that affects patients' wellbeing (Shahid, et al, 2014) and published recommended hospital noise levels for both during the day and at night (Berglund, et al, 1999). All reviewed literature relating to hospital noise shows that levels exceed these recommendations.

Excess noise is also a problem for hospital staff. In many careers noise may affect one's concentration and communication, lead to fatigue and in some cases, a permanent noise-induced hearing loss (Stansfeld & Matheson, 2003). In a hospital setting, surgeons and anaesthetists are commonly exposed to high levels of noise, in some cases exceeding the widely recognised maximum daily dose of 85dB(A) over an 8-hour working period (Department of Labour, 1995).

Only two previous studies of hospital noise have been published in New Zealand. Liddell (2008) measured the noise levels during anaesthesia administration at Palmerston

North Hospital using dosimeters worn by the anaesthetist. Love (2003) conducted his study in Tauranga, New Zealand by placing a dosimeter on orthopaedic surgeons during full hip and knee replacement surgeries. These papers will both be discussed in further detail in section 1.7.

1.2 Noise pollution

Sound is a form of communication for most living creatures, helping convey ideas and thoughts in the modern world. However, more sound does not necessarily mean more communication. Too much sound may have a negative impact on living creatures, sometimes causing disturbance and even pain when too loud. Unwanted sound is thus referred to as “noise”, conveying no meaningful information (Kryter, 1970). “In a way that is analogous to second-hand smoke, second-hand noise is an unwanted airborne pollutant produced by others; it is imposed on us without our consent, often against our wills, and at times, places, and volumes over which we have no control,” (Goines & Hagler, 2007).

As technology develops so does the level of noise. This can be attributed to population growth, urbanisation and the development of more mobile and automated technology. Goines and Hagler (2007) report that in 1991 environmental noise increased by 10% over the 1980s. A US Census administered in 2000 found 30% of Americans complained about noise, 11% found it bothersome and 40% of complainants wished to change their place of residence because of noise levels (Goines & Hagler, 2007). A French study completed in 1997 showed that 10% of the population lived in a noisy environment (over six million individuals). These levels were above 70-80dB $L_{Aeq(8-20hr)}$, well above the recommended noise levels for a home environment (Muzet, 2007). This study reports that noise levels have only risen since the 1997 investigation. The effects of noise in the hospital and workplace will be discussed in more detail in sections 1.5 and 1.6.

1.3 Characteristics of sound

Sound is both a physiological and psychological phenomenon (Yost & Nielson, 1997). Physiologically, sound is vibration that propagates through a medium, most commonly air, and passes through a series of transformations within our auditory system to become what we perceive psychologically as sound. Sound has multiple characteristics that shape the way we distinguish information. The most commonly known of these are frequency (perceived pitch, measured in Hertz (Hz)), sound pressure (perceived loudness, measured in decibels (dB)) and tonal characteristics. These characteristics, including duration of exposure, are all components that can make certain types of noise more disturbing than others.

1.3.1 Sound pressure

Sound pressure is measured using metrics and weightings that depend on the purpose of the measurement. Sound is typically measured in dB referenced to 20 micropascals (Martin & Clark, 2012). All frequencies are not perceived with the same loudness at the ear therefore weighting curves were designed to bring the loudness perception of different frequencies closer together. These were derived from the Fletcher and Munson (1933) equal loudness contours (appendix 6).

Environmental and specific noise measurement is often measured with an A-weighting filter curve (dBA). The dB(A) filter accurately reflects the frequency response of the human ear to sound, while the dB(C) filter is more linear and closer to the sound pressure level measured (Love, 2003). For high amplitude sounds and peak sound pressure level, C-weighting is often used. Studies have shown that for very low frequency noise, the A-weighting filter may be inappropriate as it underestimates frequencies below 50Hz (Leventhall, 2004). However, two studies comparing dB(A) and dB(C) filters for annoyance show this difference is not significant (Kjellberg, Tesarz, Holmberg & Landström, 1997). The

first study found no significant difference in annoyance found between the filters for low and high frequency sounds (25Hz-12,500Hz) and the second study found a significant, though small, explanation for a difference of annoyance when using different filters.

Landström, Åkerlund, Kjellberg & Tesarz (1995) investigated the annoyance of noise in varying workplace environments and whether the sound pressure level significantly affected the disturbance felt between pure-tones and broad-spectrum noise. They found that only 20% of measured annoyance related to the sound pressure level. More disturbance was found to correlate with other properties of sound such as tone, with results especially affected by the differences in environment.

1.3.2 Frequency

The frequency range of human hearing is generally between 20Hz and 20,000Hz, however, most speech information is between 500Hz and 8,000Hz (Berglund, B., Hassmén, P., & Job, R. 1996). Kryter (1970) plotted the sound pressure level required to obtain equal annoyance at different frequency bands. Each sound pressure level was relative to give equal loudness as per the Fletcher and Munson (1933) scale. The average of all five participants tested seemed to show that a lower sound pressure level was needed for high frequencies to be as annoying as low frequencies, however, there was a greater standard deviation (*SD*) between participants in both very low frequency and very high frequency stimulus bands. This study would need more participants to be conclusive.

A second study by Kryter & Pearsons (1963), cited in Kryter (1970) compares “noisiness” and “loudness” of frequency bands. This study showed perceived “noisiness” was higher than “loudness” for low-frequency sounds and vice versa for high-frequency sounds. Landström (1990) found that fatigue was higher among workers in the presence of low-frequency noise compared with high-frequency. A conclusion from these studies could be

that lower frequency sounds may cause more annoyance than high-frequency sounds of the same sound pressure level.

Noise in the low-frequency range (10 to 200Hz) can be extremely disturbing to those with more sensitive auditory systems or sensory responses (Leventhall, 2004). Participants in laboratory and community studies mentioned in Berglund, et al (1996) showed greater negative subjective responses and physiological reactions to low-frequency sound than high-frequency.

There can be many causes of unwanted low-frequency noise. Within a home or work environment, sources are often appliances such as fans or compressors which can affect concentration levels. In louder environments, this noise can be caused by car tyres and road noise, wind turbines, construction tools and other artificial sources (Berglund, et al, 1996). Low frequency noise is also a problem in modern society due to its long wavelength and efficient propagation. Attenuation of sound at different frequencies will be discussed in section 1.4.2.

People often have trouble differentiating meaningful speech from competing speech or noise due to the upward spread of masking, especially if they have a hearing impairment (section 1.6.6). The upward spread of masking means lower frequency sound often masks higher frequency sound. This compromises intelligibility as the spectrum of background noise is often low in frequency and consonants of speech are mostly mid-high frequency. A study by Miller (1947), cited in Kryter (1970) on intelligibility in narrow frequency bands of masking noise found that intelligibility (% of words correct) rapidly dropped to 0% with moderate to high intensities of masking in frequency bands under 900-1500Hz. In frequency bands over 900-1500Hz, fair to good intelligibility (45-75%) was still achieved when masking intensity was very high. The higher the masker frequency band, the more intelligibility was preserved. Kryter (1970) also states that the intelligibility of speech in

noise is affected strongly by the chance of associated word occurrence. The more information given in a sentence is directly correlated with ease of being masked by surrounding noise.

1.3.3 Pure-tone

A pure-tone is a sound that is a continuous sinusoidal waveform. Subjectively this sounds like a tone or “beep”. Kryter (1970) investigated the sound pressure levels that pure-tones and octave bands would need to be to create a 15dB temporary hearing threshold shift (TTS) and found that pure-tones created this shift at a lower sound pressure level than octave bands in all three frequencies tested. TTS will be discussed further in section 1.6.6. Kryter (1970) also reports that sounds within a narrow frequency band were more annoying than broader spectrum sounds.

Landström, et al (1995) also found that noises with tonal components were more annoying, independent of frequency, than broad spectrum noise. Annoyance increased when there were several tones present. However, the same noise has a different level of annoyance depending on the circumstances the person is in. For example, a person in hospital will have a different tolerance than a person working in a noisy environment. The annoyance aspect of pure-tones may also be used to people’s advantage. Hospital alarms are mostly tonal in nature, therefore gaining direct attention from nurses and other staff who may be monitoring a patient’s status. Alarms will be discussed in further detail in section 1.5.4.

1.3.4 Impulse noise

Sudden and loud impulse noise often causes a larger subjective reaction of disturbance than a continuous sound of the same sound pressure level (Berglund, et al, 2004). Impulse noises may damage the auditory system in qualitatively different ways to continuous noise in that the cochlea (inner ear organ) may suffer mechanical damage with exposure to

severe loud impulse sounds (Henderson, Farzi & Danielson, 1990). Continuous loud noises may cause an increase in TTS of 1.7dB per additional 1dB of noise exposure, however the effect with impulse noise was not as linear. For impulses between 99-119dB, the TTS grew at around 1.5dB per additional 1dB of noise; for impulses above 119dB the TTS grew to approximately 5dB of hearing loss for each additional 1dB of noise. It was unclear whether this may be compounding mechanical damage or a critical noise level (Henderson, et al, 1990).

Ryherd, Ocku, Tsu and Mahapatra (2011) report that peaks in sound can contribute significantly to annoyance within hospital settings. They measured both L_{eq} (equivalent continuous sound level) and “occurrence rate” of peaks within two wards of a hospital, finding no significant difference between the L_{eq} measurements but a large difference in peaks and fluctuations of each ward. “Occurrence rate” analyses what percentage of time L_{Peak} and L_{Max} noise levels exceed certain limits. L_{Peak} in Ward A exceeded 90dB(C) 47% of the time whereas only 20% in Ward B. This was significantly correlated with surveys of nurse perception of annoyance administered in both wards. This enforces the theory that noise levels must be supplemented with peaks and spectral data in order to analyse the effects of noise fully (Ryherd, et al, 2011).

1.4 Noise measurement

Modern sound level meters are able to measure the sound pressure level of an environment and convert this into whichever weighting system the user needs. Many of these also calculate specific parameters to help with data analysis, most commonly the A-weighted equivalent continuous noise level over an 8-hour working period ($L_{Aeq(8hr)}$) and the C-weighted peak noise level (L_{Cpeak}). The World Health Organization (WHO) and the Environmental Protection Agency (EPA) state that any sound level measurements should be

taken under normal noise circumstances (Berglund, et al, 1999; US Environmental Protection Agency, 1974), which involves briefing any staff or occupants on undergoing normal routines and practices regardless of the presence of microphones.

1.4.1 Reverberation time

Reverberation time (RT60) refers to the amount of time it takes for a sound to reduce from its original level by 60dB in an area. RT60 is typically calculated by the production of a loud sound at different frequencies and measuring the time it takes to decay once sound production has ceased. Gastmeier and Aitken (1999) suggest calculating the room volume at 500Hz or 1000Hz as these are typical frequencies of speech.

Reverberation time is dependent on the surfaces of the space and the characteristics of the sound. The more absorbent a room is, the shorter the reverberation time will be, reducing echoing, distortion and reflection. Speech intelligibility is reduced when a space is highly reflective and has a reverberation time of over 3.5 seconds (Gastmeier & Aitken, 1999). Subjectively this is perceived as hearing an echo and creating competing sound. Alongside making an environment more acoustically absorbent, reducing the volume of the space also reduces reverberation time (Seep, Glosemeyer, Hulce, Linn & Aytar, 2000).

1.4.2 Attenuation

Reverberation time is one of the phenomena that is affected by the surfaces of a room. A room with highly absorbing materials (e.g fibreglass) will have better acoustic qualities than a room with harder, more reflective material (e.g wood). Higher frequency sound is absorbed much more easily than low frequency sound, which tends to reflect (Seep, et al, 2000), for example some earplugs attenuate 800-8000Hz by around 40dB, but frequencies below 800Hz only attenuate by 5-25dB (Harris, 1979).

In a hospital environment, materials with higher absorption have been proven to increase sleep and reduce cardiovascular arousals and re-hospitalisation (Ryherd, et al, 2011). Shahid, et al (2014) recommend Formica, woollen cloth and carpet for hospital sites due to their higher absorption coefficients compared to other materials tested at the Rabia Trust Hospital, Faisalabad, Pakistan.

Hagerman, et al (2005) used two different sets of ceiling tiles in a study conducted in an intensive coronary heart unit, one very reflective, made from 13mm solid painted plaster-board tiles and one made from 40mm Ecophon® sound-absorbing material. Each material was in the unit for four weeks. In the two patient rooms, sound levels decreased by 5-6dB, reverberation time reduced from 0.8-0.4s, speech intelligibility scores increased and more positive subjective comments were made when the sound absorbing ceiling tiles were in place. However, there were no other physiological differences in patient vitals other than an increased need for intravenous beta-blockers in the group with poor acoustics.

1.5 Noise and the patient

1.5.1 Recommended noise levels

The WHO (Berglund, et al, 1999) recommended acceptable noise levels for a hospital care setting are 30dB L_{Aeq} at night and 35dB L_{Aeq} during the day. Night time L_{AFmax} should also not exceed 40dBA indoors. This is around the noise level of a whisper (Moore, 2013). The WHO also gives specific mention to low frequency noise, stating “a lower guideline (30dBA) is recommended” and believes ICUs should be given special attention due to the critical nature of patient need.

The American National Standards Institute (ANSI) S12.2, published in 1995, recommends a neutral spectrum room criterion of 25-40 dB(A) depending on the room type.

The Environmental Protection Agency (EPA) recommends no more than 45dB(A) for a day-night sound pressure level (L_{dn}). L_{dn} is the equivalent A-weighted sound pressure level during a 24-hour period, giving a 10dB weighting from 10pm-7am.

Standards for the building of ICUs were published by The Intensive Care Society in 1997. They report that consideration must be taken in regards to building ICUs with sound deadening materials, alarm design and positioning of beds, doors and other necessities (US Environmental Protection Agency, 1974). However, they do not report any specific values for noise levels.

The UK Health Technical Memorandum (2013) reports standards for noise in healthcare environments. It contains noise criteria for external noise sources, mechanical and electrical noise sources (excluding medical equipment), insulation parameters for each type of room and audio announcement systems. Testing and validation procedures are detailed in accordance with different international standards, regulations and methods.

1.5.2 Noise and sleep

Noise has always been a cause of disruption over the centuries. In ancient Rome, chariots were banned from being transported at night due to the wheels clattering on stones and disturbing citizens' sleep, while medieval Europe covered cobbled streets with straw and earth so horse and carriages were less disruptive overnight (Goines & Hagler, 2007). Unlike being able to shut our eyes to reduce visual input, we cannot close our ears naturally to attenuate sound during sleep (Goines & Hagler, 2007).

The amount of time we sleep per night is easily reduced by the time we take to fall asleep and the number of times we reawaken prematurely. Intermittent noises with peaks of above 45dB(A) can increase the time taken to fall asleep by around 20 minutes (Öhrström, 1993). The depth of slumber is also decreased after the first five hours, allowing loud noises

in the early morning to wake the sleeper and prevent them from falling back asleep (Öhrström, 1993). In agreement, Muzet (2007) explains sleepers are more likely to awaken in chronological sleep stages three and four, rather than one or two. The chance of awakening also relies on the noise stimulus. For example, an intermittent or sharp rising noise will be more disruptive to sleep than a continuous hum. Any noise with significance, such as the sleeper's name or an alarm tune will usually be more effective at waking the sleeper than an insignificant noise of equal sound pressure level.

One of the main reported disturbances in hospital conditions is the noise level (Hume, et al, 2010; Stansfeld & Matheson, 2003). The ability to sleep well is imperative for a patient's physical and psychological homeostasis during a critical recovery period. The lack of a full sleep will result in tiredness in the following days, fatigue and the need for compensatory rest periods (Muzet, 2007). Horne (1988) reports the main purpose of sleep to be tissue restoration through protein synthesis and cell division. McCarthy, Ouimet & Daun (1991) report that 70% of growth hormones are secreted during sleep. These are important components in wound healing, therefore post-surgery patients in the ICU who do not get adequate sleep may not heal as efficiently, prolonging hospital stays. The presence of noise during sleep may produce negative cardiovascular effects (Muzet & Ehrhardt, 1978; Muzet, Ehrhardt, Eschenlauer & Lienhard, 1981), changes in sleep pattern and compromised immunity (Brown, 1991).

1.5.3 Physiological and psychological effects

Noise can induce subjective and/or physiological stress on patients in hospitals (Hsu, et al, 2010; Topf, 2000). Past studies have assessed this stress through nurse monitoring, patient interview and surveys. Noise can evoke adverse physiological responses such as tachycardia, hypertension, dyspnoea, insomnia, thyroxin, adrenalin increases, delayed wound

healing, heightened blood pressure and heart rate, increasing complications and longer hospital stays; while psychological symptoms include annoyance, fatigue, impatience, rage, frustration, discontent, excitement and uneasiness (Hsu, et al, 2010; Hsu, Ryherd, Persson & Ackerman, 2012; Stansfeld & Matheson, 2003; Shahid et al, 2014; Topf, 2000).

McCarthy, et al, (1991) studied how noise delays wound healing. They found noise exposure increased levels of adrenaline and cortisol, impacting the endocrine response of cell metabolism and tissue repair. This is due to the endocrine aspects involved with stress hormones. Stress hormones also affect insulin levels, therefore wound healing and resistance to infection are compromised further in those with diabetes.

Community surveys have previously shown those who were exposed to higher noise levels were more likely to report the presence of “headaches”, “restless nights” and being “tense and edgy” (Stansfeld & Matheson, 2003). Reference is also made to the increasing number of patients who are being hospitalised for cardiovascular disease and receiving surgery (Hsu, et al, 2010). Many of these patients are placed in the ICU post-surgery for monitoring during recovery, however, the systems that are used for monitoring often produce noise levels around 70dB(A) (Topf, 2000), potentially creating adverse effects.

Hume, et al, (2010), report a variation in noise perception and disturbance between subjects, primarily linked to psychological differences. The level of psychological annoyance is correlated to the relationship that exists between the noise stimulus and the person (Muzet, 2007). This means that a patient on a neighbouring hospital bed whose friends, family, nurses or alarms are the source of noise are more likely to cause distress than if these were your own.

Hume, et al (2010) also reports levels of 30-40dB(A) cause “primary effects” of noise on normal sleeping subjects and “adverse effects” on more vulnerable groups, while 40-55dB(A) invokes a “sharp increase of adverse effects” on normal subjects while vulnerable

groups are “severely affected”. ‘Vulnerable groups’ may include sick or recovering patients, the elderly and those with auditory processing disorders, intellectual/physical disabilities or mental health disorders. These findings agree with the WHO guidelines on noise levels (Berglund, et al, 1999).

Stress is an important factor in noise perception and Topf (2000) reports some non-auditory factors in stress management. Personal factors include sensitivity to sound, personality dispositions, perceived social support, perceived staff support, greater pain levels and compounding stress due to other events. Some ambient stressors may include light, temperature and air quality within the ward (Topf, 2000). Differences in age and culture may affect how someone perceives noise; teenagers and younger patients have a larger tolerance to noise than those of an older age group, different cultures prefer quiet solitude for reverence and women are more sensitive to sound disruption than men (Topf, 2000). However, these findings were not directly related to hospital noise.

The aforementioned consequences of noise may also increase the amount of pain medication a patient needs and their length of stay within a hospital. Fife and Rappaport (1976) compared responses from cataract surgery patients who had no pre-existing health conditions and undergoing treatment in a hospital during building construction. At one year prior to construction, one year during construction and one year after completion of construction, it was found that noise from directly outside the patients’ windows affected how long patients needed to recover and increased the chance of rehospitalisation three months after discharge.

1.5.4 Hospital noise levels

Topf (2000) found that most critical care unit (CCU) equipment produces sound levels near 70dB(A), which they relate to heavy traffic or a noisy restaurant. Hospital ICUs

have a very individual acoustic environment; alarms, heating, air conditioning, occupant sounds and machine noise all contribute to the overall noise (Ryherd, et al, 2011). Much of this noise is for patient benefit but simultaneously can be one of their concerns. The purpose of alarms is to communicate a deviation from “normal” patient status, improving safety and staff attention (ACCE, 2006). However, a pilot study by Atzema, Shull, Morgundvaag, Slaughter and Lee (2006) showed that 99.4% of alarms were “false” and only 1% indicating the need for a change in patient management.

Konkani, Oakley & Bauld (2012) state that false alarms are a significant issue due to nurse desensitisation, allowing less importance to be placed on alarms and thereby compromising patient safety. In the six-year period leading to 2011, there were 119 deaths reported in the media that were attributable to alarm malfunctions or staff not hearing the alarm. With high levels of alarms sounding per patient per hour (2.1 ± 0.8), it is easy in an ICU environment for nursing staff to get confused with localisation of alarm sounds (Konkani, et al, 2012). Alongside behaviour modification, the need for control over medical devices is indicated.

Busch-Vishniac (2005) report a rising trend in noise levels over the last 40 years (appendix 7). Daytime levels were rising at 0.38dB per year, while night-time levels were rising 0.40dB per year. As hypothesised in Ryherd, et al (2011), some differences in results may be due to the advances in sound level meter technology. Sound level meters are now able to measure and average in shorter time periods and can measure sound levels for a much longer period of time.

Table 1.1 lists some results from international studies on noise in ICUs and relates these to WHO (Berglund, et al, 1999) guidelines, suggesting changes need to be made. These changes will be discussed further in section 1.8.

Table 1.1. Methods and results of noise measurement in ICUs worldwide and whether they meet WHO guidelines (Berglund, et al, 1999).

Date	Author	Hospital	Methods	Results	Met WHO guideline?
2005	Busch-Vishniac, et al	Johns Hopkins Hospital, Maryland, US	$L_{Aeq(1min)}$, octave-band SPLs, 24 hr measures at 3 places per unit	L_{Aeq} for 5 different locations were between 50-60dB(A), >WHO recommended L_{max} .	No
2007	Christensen	9-bedded ICU, regional teaching hospital	Only ICU, raw data over 3 consecutive days, 5-min intervals. A_v and mean dBA.	Mean = 56.42 dB(A); spikes reaching 80 dB(A); varied between days of the week	No
2013	Darbyshire & Young	5 ICUs in the UK	1 SLM at patient's head level, 1 SLM central in room. 24 hour measures, sample $L_{Aeq(1min)}$ and L_{peak}	> 45 dB(A) for all recordings, 52-59dB L_{A50} . L_{peak} was >85 dB(A) around 1-2mins/hr.	No
2010	Hsu, et al	Tertiary medical centre, Northern Taiwan, ICU	Psyc/physiological measures, average L_{Aeq} , L_{Amin} , L_{Amax} measured. Type 2 SLM used.	L_{Aeq} = 59-60dB(A), L_{Amin} = 53-55dB(A), L_{Amax} = 77-81dB(A). Annoyance and insomnia. Noise signif with heart rate and blood pressure	No
2010	Lawson, et al	Portland VA Medical Centre, ICU, US	B&K SLMs 6 inches above pillow, L_{Cpeak} (alarms) and $L_{Aeq(15min)}$ during 24hr period. *Vacant room used.	Patient door closed = 40dB L_{Aeq} , open = 45dB L_{Aeq} . Meaningful sound (speech) more disturbing than mechanical noise	Marginal
2007	MacKenzie & Galbrun	2x ICU, 1 x high dependency unit, Edinburgh, UK	$L_{Aeq(1min)}$ over 24hours, RMS L_{AFmax} – noise sources observed in person	Noted Hawthorne effect, overall 3 hospitals L_{Aeq} = 54-59dB(A), L_{AFmax} = 71-73dB(A)	No
2011	Salandin, Arnold & Kornadt	2 x ICU, Germany	Staff survey, 48 hour period, L_{AFeq} , L_{AFmax} , L_{AFmin}	Bkgd noise = 50dB(A). L_{AFeq} = 53-59dB(A) at day, 49-55dB(A) at night. Alarms = 90dB(A). A_v 6 peaks/hr over 70dB(A).	No
2013	Sen, Weitao & Zheng	General Hospital of Tianjin Medical University	Staff survey determined where to measure noise, 6 locations, L_{Aeq} , L_{Amax} , L_{Amin}	L_{Aeq} = 65-77dB(A), L_{Amax} = 85-95dB(A), L_{Amin} 51-67dB(A)	No
2013	Xie, Deng & Kang	Yibin 2 nd People's Hospital, China; Northern General Hospital, Sheffield, UK	RTs measured, $L_{Aeq(24hr)}$, day L_{Aeq} and night L_{Aeq} for 13 units in the hospital;	China: $L_{Aeq(24hr)}$ = 57-64dB(A). Night-time L_{Aeq} = 36-57dB(A), daytime L_{Aeq} = 58-66dB(A). UK: 45-60dB $L_{Aeq(24hr)}$. Day and night not reported for UK.	No

1.5.5 Subjective opinion and questionnaires

Previous studies have used questionnaires and interviews to gauge patients' perception of noise. Liu and Tan (2000) interviewed elective orthopaedic, ear nose and throat, general and gynaecology patients who had received general anaesthesia for their operation. Interviews were conducted 24-hours post-surgery with regards to their perception of sound in the operating room and recovery ward. They asked whether they found the operating room noisy, if the sound levels caused them distress, and whether they would have preferred softer or louder sound levels. Approximately one third of patients found sound levels noisy, and one out of six patients felt these levels caused them distress. Half the patients would have preferred a quieter environment.

Deng, Xiao and Kang (2013) distributed a survey to staff and patients in a Chinese hospital. Staff responses from most wards indicated they felt the greatest noise sources were patients' visitors. ICU staff were the exception in this case, observing that alarms and monitors were the loudest cause of noise. This may be due to the nature of the ICU not allowing visitors except within certain time-frames and patients needing more intensive monitoring.

Marqués, Calvo, Mompart, Arias and Quiroga (2012) created a questionnaire to send around five hospitals in Spain. This was directed at patients' noise perception and disturbance. Of the 193 respondents, 68% reported noise stopped them from sleeping, 38% and 31% reported noise was most disturbing when they wanted to rest and when they were in pain respectively. A further 35% of participants reported that sources of noise were most 'annoying' when they were repetitive, while another 28% reported this was in the presence of very loud noises. A landslide 65% of respondents reported noise was the most 'unbearable' when the stimulus was loud speech, echoing earlier claims that "meaningful noise" causes the most disruption (section 1.5.2).

1.6 Occupational noise

1.6.1 Recommended noise levels

For protection and preservation of staff members' hearing, the Health and Safety in Employment Regulations (Department of Labour, 1995), the International Standards Organization (ISO 1999:2013) and the National Institute for Occupational Safety and Health (NIOSH 1998) state that noise levels must not exceed an $L_{Aeq,8hr}$ of 85dB(A) over an eight-hour working day, nor should any individual noise spike exceed 140dB (unweighted). If noise levels are in excess of these values, the chance of developing a noise-induced hearing loss becomes greater with protracted exposure. The NIOSH (1998) also report an exchange rate of -3dB must be used for time-weighted-averages during measurement of occupational noise, as sound pressure is measured on a logarithmic scale. This means for every doubling of the 8-hour work shift, the L_{Aeq} allowance reduces by 3dB, and for every halving, an extra 3dB is allowed. Table 1.2 demonstrates this rule below.

Despite the guidelines in sections 1.5.1 and 1.6.1 being in place, there is very little evidence of building planning or behaviour modification for control of noise issues within hospitals or workplaces. This may be due to budget constraints, conflicting opinions within teams or the lack of an international standard for interpreting/weighting noise (Shahid, et al, 2014).

Table 1.2. Equivalent noise level and corresponding exposure time (Liddell, 2008).

85dB(A)	8 hours
88dB(A)	4 hours
91dB(A)	2 hours
94dB(A)	1 hour
97dB(A)	30 minutes
100dB(A)	15 minutes
103dB(A)	8 minutes
106dB(A)	4 minutes
109dB(A)	2 minutes
112dB(A)	1 minute
115dB(A)	30 seconds

1.6.2 Noise and cognition

Noise in hospitals also has an effect on staff who work in these environments. Nurses and surgeons are exposed to unregulated noise on a daily basis, especially when working in an operating theatre. Murthy, Malhotra, Bala and Rughunathan (1995) found that mental efficiency and short-term memory decreased when subjects were exposed to noise. Trail-making, digit symbol and Benton visual retention tests were administered to 20 anaesthetists who had a mean age of 27.7 years. Each test was spaced with a week in between to reduce practice effects. Mean scores decreased from 22.9 to 16.35 for the trail making test, from 83 to 74.05 for the digit symbol test and from 9.55 to 5.8 for the Benton visual retention test when noise was present. All decrements were statistically significant ($p = <0.05$).

Noise can also induce fatigue, leading to a compromise in quality of work (Stansfeld & Matheson, 2003). This may be due to poor intelligibility have consequences such as wrongly naming medications that sound similar. In laboratory experiments it has been discovered that when the noise stimulus is speech, the signal is less likely to be understood or remembered. However, when the noise was a non-speech stimulus this effect was not present (Stansfeld & Matheson, 2003). The WHO (Berglund, et al, 1999) reports further intelligibility issues when speaking with patients about recovery methods and instructions stating that speech is 100% intelligible with background noise levels of 35dB(A) and fairly understandable in levels of 45dB(A). When levels are around 65dB(A), more vocal effort must be used for sufficient intelligibility.

Way, et al (2013) conducted speech-in-noise tests on normal-hearing surgeons who had to repeat one word back at a time. They found that the participants performed more poorly in music than in quiet or filtered noise and also when they were tasked with a job as opposed to not being tasked.

Annoyance thresholds were found to be approximately 6dB lower when participants were completing complex reasoning tasks as opposed to simple reaction-time tasks (Kjellberg, Landström, Tesarz, Söderberg & Åckerlund al, 1996). As reported with patient consequences, annoyance during work is also heightened when the noise stimulus is irrelevant speech, especially during tasks involving language such as proof-reading or assessing results.

1.6.3 Physiological effects

Those who are chronically exposed to excessive noise, even if lower than the levels reported in table 1.2, tend to have higher blood pressure and greater chance of hypertension than those who are not, however, for a significant correlation 20-25 years of occupational

noise exposure was needed (Lang, Fouriaud & Jaquinet-Salord, 1992). A meta-analysis conducted by van Kempen, et al (2002) discussed how noise exposure affected people physiologically. They assessed 43 occupational and community studies with varying effects such as blood pressure and hypertension and found systolic blood pressure increased significantly when subjects were consistently exposed to occupational noise. This finding was not present in the community studies that assessed traffic noise, indicating blood pressure increases may be an occupational effect.

1.6.4 Hospital noise levels

Noise levels differ between different types of surgeries, especially with the development of new equipment (Ginsberg, et al, 2013). Sound levels have typically been the highest in orthopaedic and neurology surgeries, with previous studies showing L_{Cpeak} levels exceeding 100dB 43% of the time in orthopaedics and 39% of the time in neurology (Kracht, Busch-Vishniac & West, 2007). In other surgery types L_{Cpeak} levels exceeded 100dB under 40% of the total time.

Fitzgerald and O'Donnell (2012) measured noise in orthopaedic surgeries that anaesthetists are exposed to. They found that noise exceeded 65dB(A) 22% of the time and exceeded 80dB(A) less than 1% of the time. Staff conversation was the source of 30% of all peaks over 65dB(A), however, only 54% of this was with the patient or patient-related. The handling of metal tools and medical equipment was the source of 20% of all peaks over 65dB(A). Table 1.3 compares noise levels from multiple studies in operating theatres.

Ginsberg, et al (2013) studied noise levels in different stages of surgery. They found anaesthetic technicians suffered from the most noise compared with surgeons or nurses working on the patient during the procedure itself.

Table 1.3. Methods and results of noise measurement in operating theatres and whether they meet Health and Safety in Employment Regulations (Department of Labour, 1995).

Date	Author	Hospital	Methods	Results	Met DoL standard?
2012	Fitzgerald & O'Donnell	St Mary's Orthopaedic Hospital, Cork, UK	SLM measured noise every second for whole day in theatre.	Mean=63dB(A), max=92.8dB(A). Noise >65dB(A) 22% of time, >80dB(A) less than 1% of time. Conversation/instruments causes.	Yes
2013	Ginsberg, et al	A University Hospital, not reported.	23 surgeries with anaesthesia in 7 stages: set-up, induction, skin incision, 60mins after incision, termination of circulation, emergence & transport. Max dBA for 2min period.	All max levels >80dB(A), induction & transport >90dB(A).	Yes
2008	Liddell	Palmerston North Hospital, New Zealand	Dosimeter + SLM, L_{Aeq} & L_{max} for all theatre types.	Highest L_{Aeq} & L_{max} in MRI, Dental, ERCP (>78dBA; 106-114dBA). Ortho: L_{Aeq} = 73dB(A), L_{max} = 106dB(A).	Yes
2003	Nott & West	Royal West Sussex Hospital, UK	Mean & max dBA recorded in 59 orthopaedic surgeries with SLM on slow response.	Loudest = total knee replacement (max 101dBA, mean 92dBA). Saws, metallic bin lid, air compressor detachment >100dB(A). All means between 75-95dB(A).	Marginal
2007	Sydney, et al	Queensland, Australia	Simulated total knee operation with two different saws, measured with SLM.	L_{Aeq} = 81.6-88.9dB(A) between saw types.	Marginal
2007	Tsiou, Efthymiatos & Katostaras	9 Greek hospitals	L_{eq} , L_{peak} measured with SLM	Maximum L_{eq} measured 71.9dB(A); L_1 =84.7dB(A); L_{10} = 76.2dB(A); L_{99} = 56.7dB(A); peaks 99-106dB(A).	Yes
1991	Willett	Charing Cross Hospital, UK	SLM and frequency analyser used to measure peak noise at ear and 3m away.	All tools gave noise >90dB(A) except dental burr (80dBA). Freqs between 2.5-6kHz except multihead drill (1.4Hz).	Yes

1.6.5 Subjective opinion and questionnaires

Bayo, Garcia and Garcia (1995) measured noise levels in a Spanish hospital and administered 20-question surveys to 295 staff members. Noise was predominantly between 60 and 64dB(A) during the morning measurement period and 55 to 59dB(A) in the afternoon period. Staff responded to surveys in three sections: their personal information and job, perception of their general work conditions and lastly noise-related questions. Professional satisfaction was rated on a continuous scale from 1 (completely dissatisfied) to 10 (completely satisfied), the mean result being 6.2 ($SD = 2.1$). A four-step scale (inappropriate, slightly inadequate, adequate, very adequate) was used for physical standards such as lighting, temperature, ventilation, space and noise. All areas returned responses of 'slightly inadequate or inappropriate' except lighting, which was deemed 'adequate' or 'very adequate'. The third scale was directed only at noise, again using a 10-step scale from 'absolutely quiet' to 'unbearably noisy' and returned a mean of 6.8 ($SD = 1.8$). A five-step categorical scale was also used to evaluate noise annoyance. No differences were found between genders ($p = .36$) or job categories ($p = .18$). Those who felt annoyed by noise were significantly higher in the age group between 31 and 50 years ($p = <.001$). Of the 295 respondents, 76% thought noise originated purely from inside the hospital, 66% created by visitors and 59% by medical care devices (Bayo, et al, 1995).

Tsiou, Efthymiatos and Katostaras (2008) found that 84% of anaesthetic technicians in Greece believed noise had a negative impact on their work. Deng, et al (2013) distributed a survey among staff and patients at a Chinese hospital, finding that staff were significantly more sensitive to noise than patients. However, between 35 to 44% of patients from different hospital departments reported that their sleep was disrupted by loud noise at least once.

Music in operating theatres has returned various results in previous studies. A study dedicated to music by Hawksworth, Asbury and Miller (1997) report 51% of their 144

anaesthetists felt music was a distraction in theatre and 26% preferred to work in silence. However, they also found an increase in ability to detect trends in vital signs when music was played at a moderate level, despite participants preferring to work without it. On the contrary, Ullman, et al (2008) found it to have a positive influence for staff. While in the operating room, 63% of staff choose to play music, with 58% of music requested being of classical genre. The desired volume of music does reduce with the increase of staff age, however 78.9% of staff indicated music s calming for them during procedures. There are few previous studies on music in the operating room, however this may show a change in attitude with time or culture.

1.6.6 Hearing loss

A hearing loss is defined as an increase in a person's hearing thresholds as determined by clinical audiometry (Goines & Hagler, 2007). Hearing loss may be caused by congenital conditions, diseases, chemicals, ototoxic drugs, accidents, the aging process and noise exposure (Berglund, et al, 1999). There are different types of hearing loss: sensori-neural (permanent damage to the hair cells of the inner ear), conductive (mechanical damage or prevention of sound propagation within the outer and/or middle ear) and mixed (both sensori-neural and conductive components within the hearing loss). Noise exposure can lead to a sensori-neural hearing loss when high levels of sound cause damage to the fine outer hair cells of the inner ear responsible for sound transmission. This is called a noise-induced hearing loss (NIHL).

A temporary threshold shift (TTS) may also occur with loud noise exposure. This may be present until the auditory system has had enough time to recover, usually a few hours. Mills (1982) found a relationship between the level of noise exposure and the magnitude of

TTS after reviewing multiple studies on chinchillas, monkeys and humans. As discussed in section 1.3.4, for each additional 1dB of noise, the TTS increases by 1.7dB.

Permanent NIHL is identified by an increase in hearing thresholds in the higher frequencies, usually affecting 3-6kHz, with the largest effect at 4kHz and rising back to normal levels at 8kHz (Berglund, et al, 1999). This is often called a “noise notch”. With continuous noise exposure, hearing may gradually deteriorate over many years and is most likely permanent. This may be due to a person’s occupation or hobbies/recreational activities such as rifle shooting or very loud music. NIHL can be called a permanent threshold shift (PTS) and sometimes occurs with tinnitus (a perception of ringing or buzzing originating from one’s ears/head). A study by Kamal (1982) tested the hearing thresholds of staff members working in orthopaedic theatres and found an average of all audiograms showed the beginnings of a noise-induced hearing loss, thought to be the by-product of pneumatic drills and saws. Just under half of the 40 subjects had a NIHL, in line with later findings of Willett (1991).

A PTS is most commonly accompanied by abnormal loudness perception (recruitment) and is also associated with tinnitus. A hearing loss affects speech discrimination, leading to impaired school and/or job performance (Goines & Hagler, 2007). Some people who have a hearing loss feel their handicap limits them from participating in activities in society, resulting in isolation from peers, loneliness and depression. For many people with hearing loss, audiological services can help with communication strategies, hearing aids and assistive devices to prevent this limitation from affecting their lives.

As previously discussed in section 1.6.1, exposure to noise above the 85dB $L_{Aeq,8h}$ may cause damage to the auditory system. Berglund, et al (1999) state that a hearing loss is unlikely below the reported levels of 85dB(A). However, it is important to note that, in accordance with aforementioned studies, noise exposure below this level still has adverse

physiological and psychological effects on sensitive or vulnerable individuals, such as those in hospital.

For any hearing threshold test, it is important that the subject has not been exposed to loud noise for at least 16 hours. This is a requirement of any hearing test being completed for an Accident Compensation Corporation (ACC) NIHL claim. The instance of NIHL in New Zealand is still increasing despite tighter health and safety regulations, according to ACC (Thorne, et al, 2008). The cost to ACC for NIHL related compensation rises at around 20% per year, costing \$193.82M over the 2005-2006 review period. The most common occupations to claim for NIHL were agricultural, fishery, trades, machine operators and assemblers. There were no figures reported for surgical staff claiming ACC compensation.

1.7 Noise in New Zealand hospitals

There is little information about hospital noise in New Zealand, with only two papers on theatre noise being published. Liddell (2008) measured the noise levels that the anaesthetic team at Palmerston North Hospital were exposed to over six months. This noise was measured using Quest Electronics Model M28 noise logging dosimeters worn on the anaesthetists. A Tecpel 331 Sound Level Meter was then used with dB(A) weighting for more specific information. Unoccupied levels in the theatres were between 46-54dB(A). Noise spikes occurred when setting up and checking the anaesthetic machine, surgical preparation and the induction of the anaesthetic. The noise that anaesthetists were exposed to during different types of procedures varied between 68-85dB L_{Aeq} and 100-114dB L_{Apeak} . Contributions to noise in the surgical theatre include anaesthetic machinery, surgical tools, theatre staff conversation and background music used to calm the patient. Liddell (2008) mentions the high noise levels in magnetic resonance imaging (MRI) and lithotripsy, in

which cases the patient and staff are provided with hearing protection. However, with staff wearing hearing protection, communication abilities are likely to be compromised.

Love (2003) states that 50% of orthopaedic personnel have early signs of NIHL due to the constant noise exposure in their workplace, in line with overseas studies by Kamal (1982) and Willett (1991). He conducted a study in Tauranga, New Zealand, measuring the noise during three hip replacement and two knee replacement surgeries. All surgeries had a noise level of between 74.8-82.1dB L_{Aeq} and spiked above 110dB L_{Apeak} . These spikes exceeded the unweighted 140dB allowance on four occasions during hip replacement surgery and three times during knee replacement surgery.

1.8 Noise reduction

Improvement in the acoustic environment was voted as the most necessary change needed in hospitals compared with temperature, humidity, lighting and air quality (Deng, et al, 2013). Questionnaires sent to patients and staff by Deng, et al (2013) proposed six main strategies for improving the hospital acoustic environment: acoustic treatment, music play, visitors' voice reduction, more single-bed wards, reduction in alarms and turning down TV volumes. Most staff members, with the exception of ICU workers, voted for the reduction in visitors' speech. ICU staff voted for better acoustic treatment and alarm noise, suspected to be influenced by the special nature of ICU noise and care.

Kahn, et al (1998) investigated noise and intervention at Rhode Island Hospital. Noise levels and sources were measured and a behaviour modification trial was completed aimed at reducing peaks over 80dB(A). This consisted of an educational session with all staff within the ICU department, discussing in detail noise pollution and the effects on patients and workers. Modifiable behaviours included turning televisions down or off, switching non-essential alarms to vibrate mode, decreasing intercom and speaker use, strictly adhering to

visiting hours and reducing unnecessary speech at the patient bedside. This was in place for three weeks, with results showing significant reductions in noise levels at most times of the day. Richardson, Thompson, Coghill, Chambers and Turnock (2009) performed a similar study, finding peaks reduced from 96dB(A) to 77dB(A) after the modification period. Their written educational guideline included topics on the importance of sleep, door entry, telephones, nurse call system and the physical characteristics of the ward. They also arranged for a staff nurse to deliver an education programme and visit/monitor wards once per week. Ear plugs and eye masks were also offered to patients for their comfort.

Wyk, Koldenhoven, Miller and Murphy (2012) give a rank order for hospital noise reduction: materials, finishes and space planning; facility equipment and maintenance; hospital technology; and administrative/behavioural modification. Issues with these were hospital finance, ease of implementation and staff attitudes on behaviour modification.

In surgeries it can be especially difficult to attenuate noise without compromising communication between staff members. If staff members wore hearing protection to ensure they did not risk damaging their hearing (section 1.6.6), communication of tool exchanges, instructions and patient monitoring would be very difficult and require more effort. Most patients who are being operated on do not need to be conscious. However, the loud noises from surgical tools may still damage their hearing even while under anaesthesia. Ravicz and Melcher (2001) studied the noise present during a magnetic resonance imaging (MRI) examination. They researched the attenuation a specialised helmet would give to the patient in addition to ordinary ear plugs. Worn together, ear plugs, muffs and the helmet attenuated noise by 55-63dB. Alone, these devices attenuated significantly less. This is partially due to how we perceive sound. With the ear plugs or muffs being worn, the patient still perceived sound through bone conduction in their body and head. Although the three devices together

are an impressive concept, they fall short on practicality. Nott and West (2003) also advised placing earplugs in patients who are to receive surgery.

In all noisy situations, especially all areas of the hospital, it is more advantageous to attenuate noise at its source. In hospitals, this may involve better insulation of medical equipment and alarms, adding rubber to metal bin lids and wheels, slowing down fan speed for air conditioners and heat pumps, using different materials for mallets and hammers during surgeries and educating staff members on noise, influencing change/awareness of routine.

The WHO guidelines (Berglund, et al, 1999) propose rules that include governmental assistance in regulating noise in all situations. Some of these include policy-relevant research, cost-effectiveness for noise-induced hearing loss claims, implementing action plans with short, medium and long-term objectives and international coordination of governments to provide leadership in this field. A main issue that contributes to governmental inaction is the different ways in which methodologies and results are reported in each paper. Notably, Shahid, et al (2014) admit their lack of acoustic knowledge and comment on many authors of previous studies being from fields of medicine or nursing, having very little acoustic experience.

The current study combines the fields of acoustics and audiology in order to effectively monitor and measure noise levels in Christchurch Hospital, New Zealand. There has been little past New Zealand research in regards to noise in hospitals, with only two relevant studies found (Liddell, 2008; Love, 2003).

1.9 Research questions and aims

The aim of this research was to measure the noise levels in Christchurch Hospital's ICU and theatres and address whether these comply with WHO guidelines and Health and Safety in Employment Regulations (Department of Labour, 1995). Research questions were:

1. Do the noise levels in Christchurch Hospital meet the corresponding written guidelines or allowable occupational noise dose?
2. How do these noise levels compare to those published in overseas studies of noise in hospitals?
3. What are the main sources of noise in selected areas of Christchurch Hospital?
4. How do staff and patients feel about noise in the hospital?

Noise levels in the ICU are expected to exceed WHO (Berglund, et al, 1999) noise guidelines of 35dB(A) (day-time) and 30dB(A) (night-time) L_{Aeq} . Staff exposure levels in the orthopaedic unit are unlikely to exceed the Health and Safety in Employment Regulations (Department of Labour, 1995) of 85dB(A) $L_{Aeq,8h}$, however they may still give cause for concern. Staff surveys may identify possible protocols changes and determine where there is a problem with surgical tool noise, while patient surveys may identify a need for better acoustical treatment of the ICU. This project will inspire future research into treatment or mitigation of this noise and strategies to meet compliance with noise standards. A tranquil, restorative and stress-free environment will reduce patients' length of hospital stay and increase staff efficiency and productivity (Fife & Rappaport, 1976; Stansfeld & Matheson, 2003).

Chapter Two: Method

2.1 Ethics Approval

Ethical approval for this project was gained by the University of Canterbury Human Ethics Committee on (Appendix 1). All procedures were completed in accordance with the approval and did not require further approval from the New Zealand Health and Disability Ethics Committee.

2.2 Participants

Participants in this study were all patients over the age of 18 years admitted to the ICU at Christchurch Hospital, New Zealand, who were willing to participate in the survey and be present for noise measurement. Furthermore, participants were also all staff members working in the ICU who were willing to participate in the survey and staff members in theatres who were willing to participate in the survey or willing to wear a dosimeter for noise measurement.

2.3 Procedure

2.3.1 ICU

The Christchurch Hospital ICU consists of nine main beds laid out in the shape of an 'L' as seen in figure 2.1. There were three private rooms adjacent to the hallway. In the centre was the nurses' station and multiple store rooms. The dependent variables in the ICU were the objective noise levels measured and the subjective responses from staff and patient surveys. Independent variables were the day of the week, time of the day and levels from each microphone. Extraneous variables include staff behaviour due to the presence of instrumentation, exterior construction noise and personal factors of survey participants such as age, department and hearing sensitivity.

Noise measurement within the ICU was conducted with a Brüel & Kjær two-channel Pulse system using two microphones. This allowed simultaneous data recording from different spaces within the ICU. All measurements were saved automatically onto a Seagate 2TB external hard drive. Statistical parameters of L_{Aeq} , L_{Cpeak} , L_{AFmin} , L_{AFmax} , L_{A10} , L_{A50} and L_{A90} were determined from the measurements. All instrumentation was set to “fast” response as stated in the WHO guidelines (Berglund, et al, 1999).

Two microphones were placed in areas of noise according to preliminary noise measurement (appendix 2). The microphones were calibrated at the beginning and at the end of noise measurement. Ideally microphones would be placed just above the head of the patient and an appropriate distance from the wall. This was not feasible due to patient equipment and safety precautions in the ICU, therefore microphones were placed on curtain railings at the ends of beds five and eight (figure 2.1). Microphone cables running from the Pulse system were secured to flat wall and ceiling surfaces using 3M hooks and tape (appendix 9).

Data was collected over one whole week, beginning at 9am on Wednesday 16th September and finishing at 9am on Wednesday 23rd September 2015. Over this period, microphone placement and equipment security was checked daily. Measurements were taken every second.

Where possible, the investigator observed potential sources of noise. Dimensions of the ICU were recorded, however reverberation times (RT60) could not be physically measured due to potential patient discomfort. Sabine’s formula was used to calculate the RT, however, the complex layout and materials of the ICU reduced the reliability of these estimates, therefore this was not done for the ICU department.

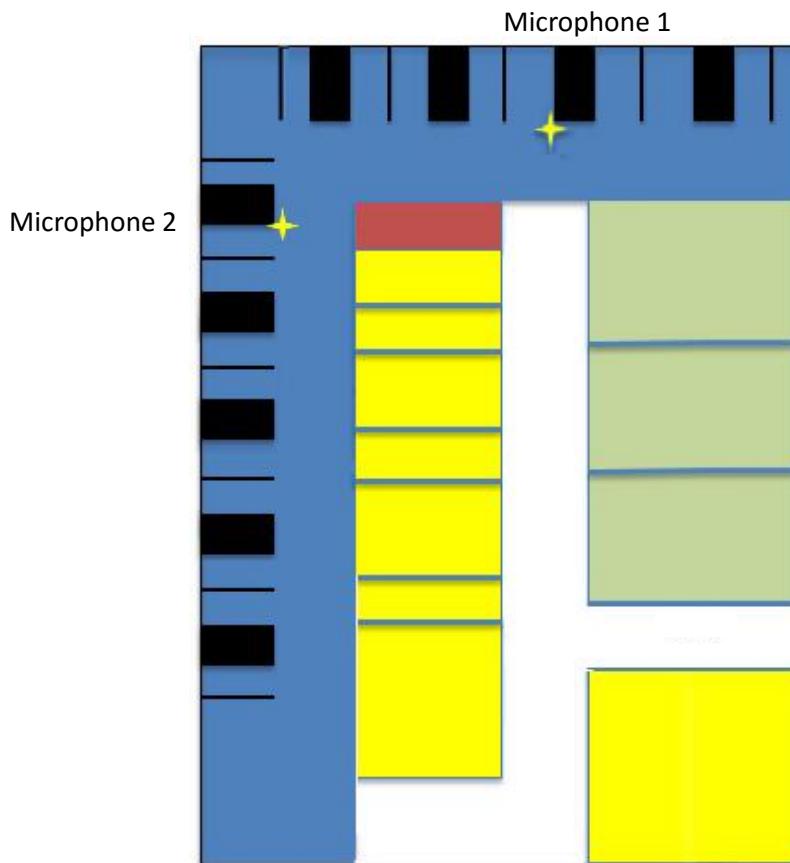


Figure 2.1. Christchurch Hospital ICU layout (not to scale).

Key: Blue = main floor, black = beds, red = nursing station/administration area, yellow = store-rooms, green = private single-bed rooms. Yellow stars = each microphone placement.

2.3.2 Surgical Unit

The surgical units where sound measurement was completed were enclosed operating theatres within the hospital. Sound levels were measured during one type of cardiothoracic surgery and three types of orthopaedic surgeries, each type being monitored at least twice.

Sound was measured with a Brüel & Kjær 2250 sound level meter being held by the investigator approximately two metres away from the patient and the sterile area of surgical tools. The surgeon in each procedure also wore a 3M NoisePro personal dosimeter that was attached to the back pocket of their scrubs with the microphone extending upwards near their ear. Both sound measurement devices calculated the statistical parameters of L_{Aeq} , L_{Cpeak} , L_{AFmin} , L_{AFmax} , L_{A10} , L_{A50} and L_{A90} . All

instrumentation was set to “fast” response and calibrated at the beginning of each surgery. Noise peaks were associated with their sources by physical observation where possible. Theatre dimensions were measured using a Leica DISTO A5 laser distance meter. The reverberation time (RT60) was estimated using Sabine’s formula and an average absorption coefficient for each material over the frequency range of 125 to 4000Hz.

2.3.3 Staff and patient surveys

Surveys of noise perception and disturbance were prepared by research associate Dr Brian Donohue prior to thesis commencement. These were to be completed at any stage, simultaneously and anonymously. Staff within the ICU and theatres filled out the staff noise perception questionnaire (appendix 4) at any stage during and after the Pulse measurement system was installed in their unit. Each survey had a consent form attached (appendix 3) that included a tick box for “active” or “passive” subject. “Active” subjects were surgeons or nursing staff who wore the dosimeters during measurement. The consent form asked for the participant’s name and signature, however, this was separated from the anonymous survey responses. The survey was a one-page questionnaire that required the participant to tick an option for each multiple-choice question. This asked their age and profession categories, however, most questions focussed on noise and asked the participant to select an answer between “strongly agree”, “agree”, “disagree”, “strongly disagree” and “don’t know” for various questions. There was also space for comment below.

In the ICU, these surveys were left in a clearly marked box in the staff room for members of their team to fill out at their leisure. There was another empty box adjacent to this for anonymous survey responses. In theatres, these were placed in their staff room and also in the pigeon holes of each anaesthetic technician. Completed surveys were placed in an

adjacent empty box in the staff room and also a box in the administration office of the anaesthetic department.

Patients were asked to complete a different survey (appendix 5). Their survey was also comprised of one-page multiple-choice questions, however, it was directed at the disturbance of noise while they were trying to rehabilitate. Surveys were initially going to be given to the nursing manager of the ICU and adjacent wards to attach with discharge papers. This was not feasible, therefore surveys were attempted to be administered verbally at the patients' bedsides once they were discharged from ICU and transferred to another ward. This returned mixed results as many patients were not cognitively able to answer questions and many could not remember their location or past events. The patient survey was omitted from the project due to minimal responses, unreliable results and a loss of confidence in this measure.

2.4 Data analysis

2.4.1 ICU data

Sound level data for two-hour periods from the ICU data using the Brüel & Kjær Pulse system were exported to Brüel & Kjær Pulse Reflex v17.1.1 data analysis software. Spectral analysis using a Fast Fourier Transform (FFT) in Reflex was completed for the two-hour periods and compared. Data for L_{Aeq} , L_{Cpeak} , L_{AFmin} , L_{AFmax} , L_{A10} , L_{A50} and L_{A90} was obtained for each two-hour period and exported to Microsoft Office Excel for tabulating. Each 24-hour period was separated into six different "times of day", each including two two-hour periods: early morning (3am-7am), morning (7am-11am), midday (11am-3pm), afternoon (3pm-7pm), evening (7pm-11pm) and night (11pm-3am). Pulse Reflex was used to calculate the number of peaks that exceeded 75dB(A) for

each “time of day”. The numbers of peaks and times of day were exported to Microsoft Office Excel and pivot charts were created.

Data from these Microsoft Excel documents was exported to IBM SPSS Statistics 23 software, where statistical analysis was completed using a linear mixed model analysis with pair-wise comparisons to determine correlations between day of the week, time of day, and microphones 1 and 2 for statistical parameters of L_{Aeq} , L_{Cpeak} , L_{AFmin} , L_{AFmax} , L_{A10} , L_{A50} and L_{A90} . Day and time of day were entered as “fixed effects” and difference in microphones was entered as a “random” effect. A Bonferroni interval adjustment was used due to multiple variables. For analysis of peak numbers within each period, independent-samples t-tests were used.

2.4.2 Surgical data

Surgical data was taken straight from the Brüel & Kjær 2250 sound level meter and the 3M dosimeter and manually typed into a Microsoft Word document. These instruments gave values for L_{Aeq} , L_{Cpeak} , L_{AFmin} and L_{AFmax} which were compared to the standards for noise exposure for an eight-hour working period.

2.4.3 Surveys

Survey responses were collected and manually entered into IBM SPSS with a hierarchical rank (1-5) for each possible response. Descriptive statistics were used to assess the population, with variance of answers in percentages extracted into a table on Microsoft Word. Spearman’s rank correlation testing was used for variance of responses due to the ordered data. The variance of participant age, years’ experience and hospital team were compared with each question separately. Any extra comments on the survey were added at the bottom of the Microsoft Word table.

Chapter Three: Results

Week-long sound level measurements taken in the ICU revealed that $L_{Aeq,2hr}$ exceeded the WHO guidelines (Berglund, et al, 1999) of 35dB(A) at all times of the day and 30dB(A) at night over the whole week of data collection. No L_{Cpeak} recorded was above the Health and Safety in Employment Regulations (Department of Labour, 1995) of 140dB, however there were a substantial number of peaks at a level that may harm staff and/or patients physiologically and psychologically. L_{Aeq} measurements nor the 140dB peak level taken in surgeries did not exceed the Department of Labour regulations (1995) of 85dB(A), however the levels indicate cause for concern. Survey results show staff would prefer noise to be at a lower level in the workplace and think current levels are sometimes too loud to concentrate and may hinder productivity.

3.1 ICU

3.1.1 Room dimensions

Room measurements for the ICU were difficult to quantify. Figure 3.1 shows the measurements between each bed curtain, hall and isolated room. The ICU is approximately 18 metres in width and 27 metres in length. The reverberation time calculation was unreliable due to the layout of connected spaces, windows and beds. Surfaces of walls and ceilings were hard plaster surface (appendix 9) while flooring was linoleum. There were machines/alarms for all nine patients on the main floor, ceiling air conditioning, a number of blood transfusion machines around the area, metal rubbish bins and carts and different medical teams/cleaning staff coming in and out. There was also a notice leading into the ICU from the staff room asking everyone to please keep the noise level down at night.

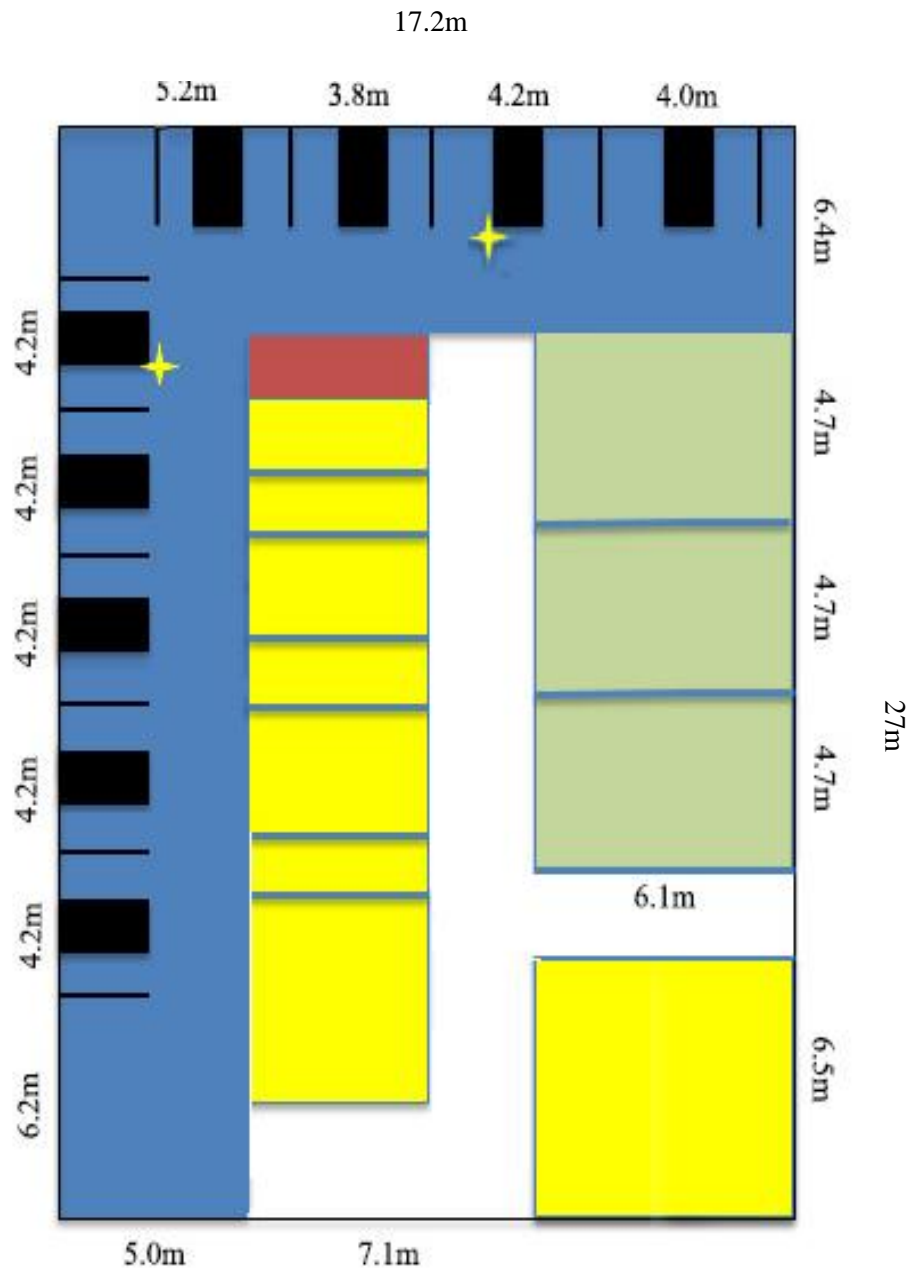


Figure 3.1. Christchurch Hospital ICU measurements.

Key: Blue = main floor, black = beds, red = nursing station/administration area, yellow = store-rooms, green = private single-bed rooms, white = hallway. Yellow stars = each microphone placement.

NB: Image is not to scale.

3.1.2 Noise measurements

Preliminary noise measurements (appendix 2) and observation showed subjective sources of peaks being alarms, trolleys, a metal bin being put down, doors slamming, chairs scraping, drawers shutting and loud speech. During this period it was noted that a few staff members were having a clearly audible conversation about an upcoming holiday beside a sleeping patient, however, most observed conversation was related to the patient. Noise levels would be lower with less staff conversation, however, subjectively the talking created an easy, positive atmosphere. A radio was on and audible from the end of the corridor. Noise at each bed varied depending on patient needs (i.e physiotherapists, radiologists coming in). During the period of sound level measurement for both preliminary studies and the week-long measurement, the current ICU was being extended in the adjacent room (through the hallway to the right of figure 3.1). This caused excess building noise and disruption for staff during this period.

3.1.2.1 L_{Aeq}

L_{Aeq} values for the ICU for each two-hour period over a day are seen in figures 3.2-3.8 below. These were all in excess of the 35dB(A) WHO guideline (Berglund, et al, 1999) for day and 30dB(A) for night.

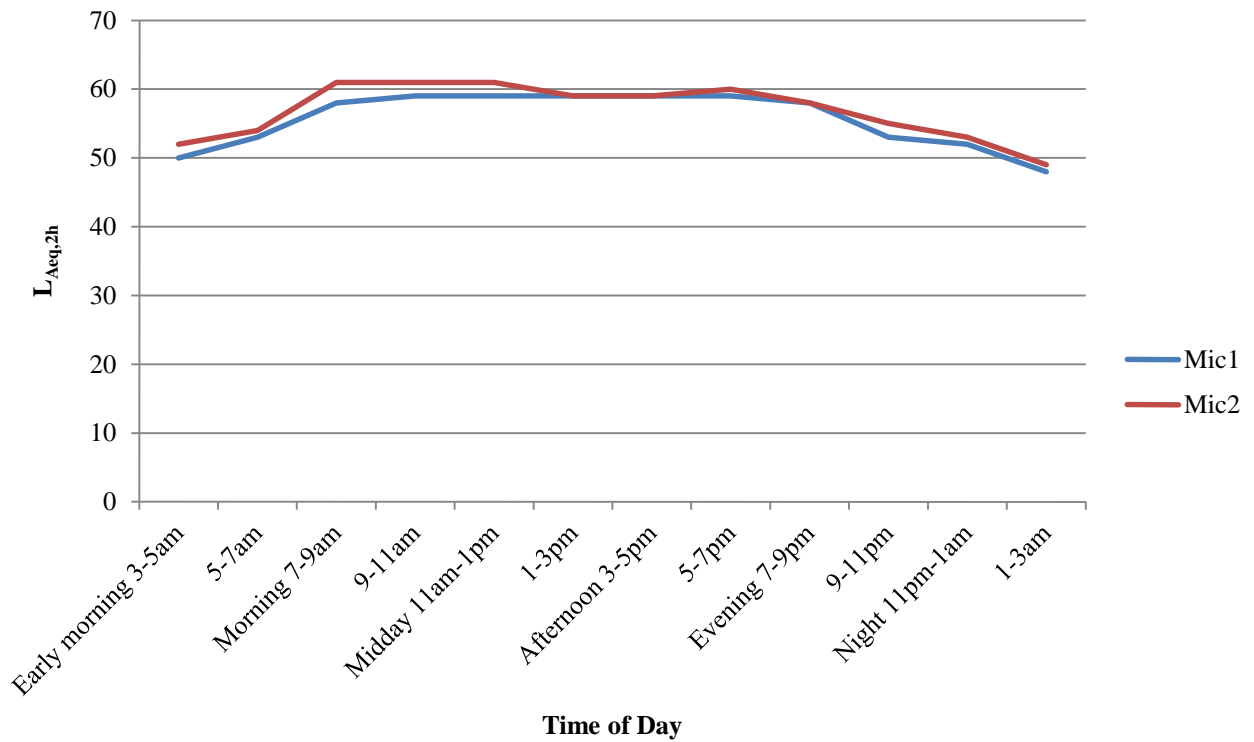


Figure 3.2. L_{Aeq} as a function of time of day for Monday 21st September 2015.

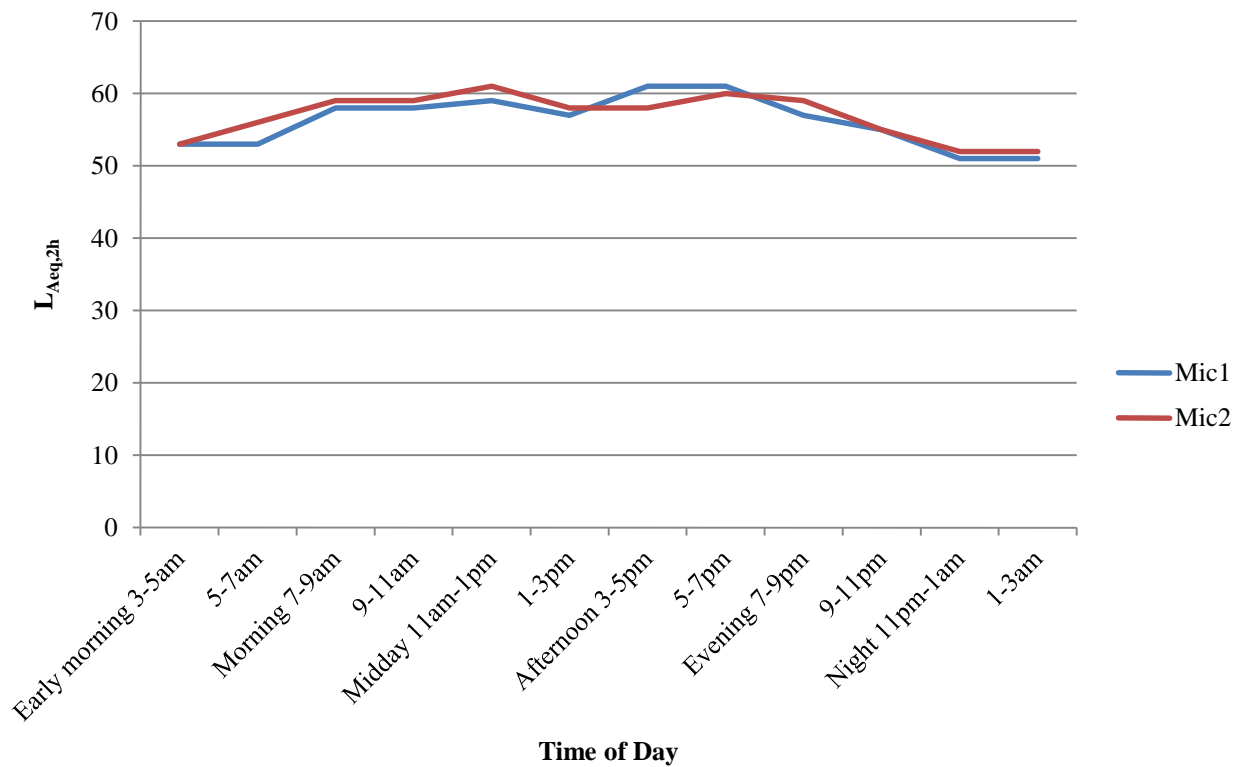


Figure 3.3. L_{Aeq} as a function of time of day for Tuesday 22nd September 2015.

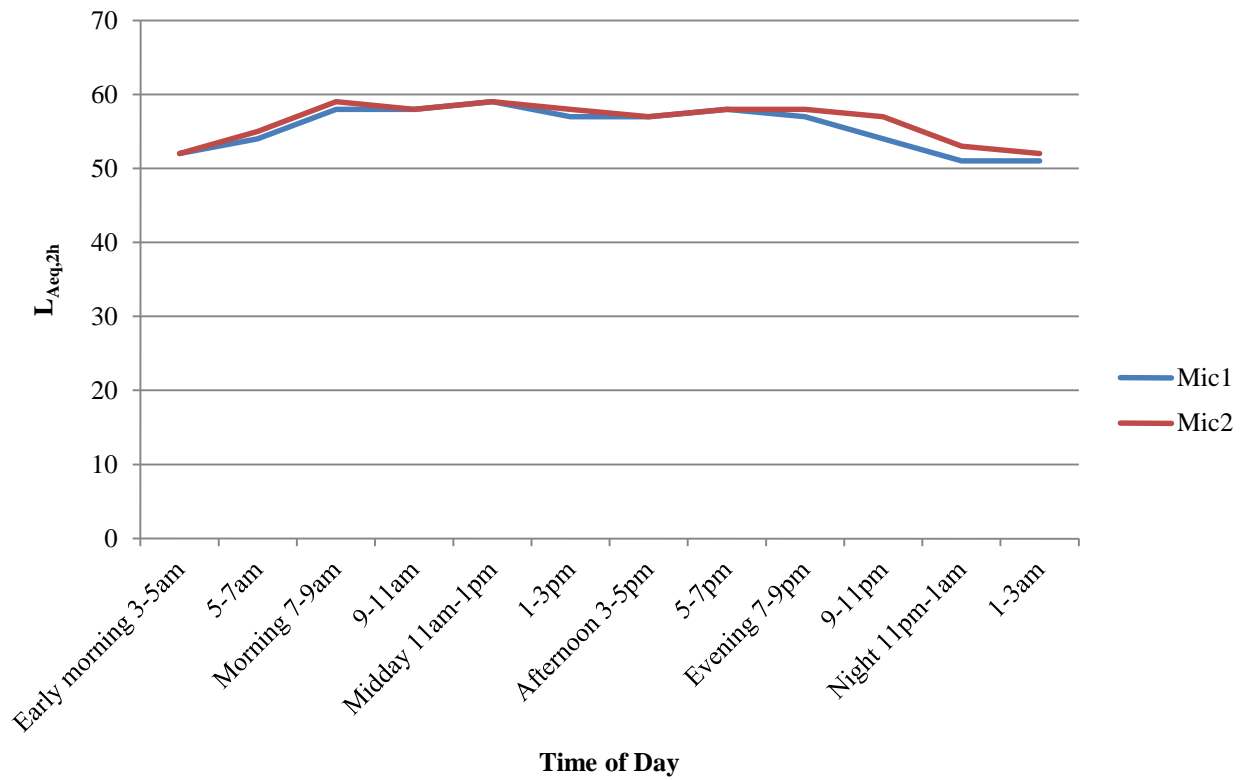


Figure 3.4. L_{Aeq} as a function of time of day for Wednesday 23rd September 2015.

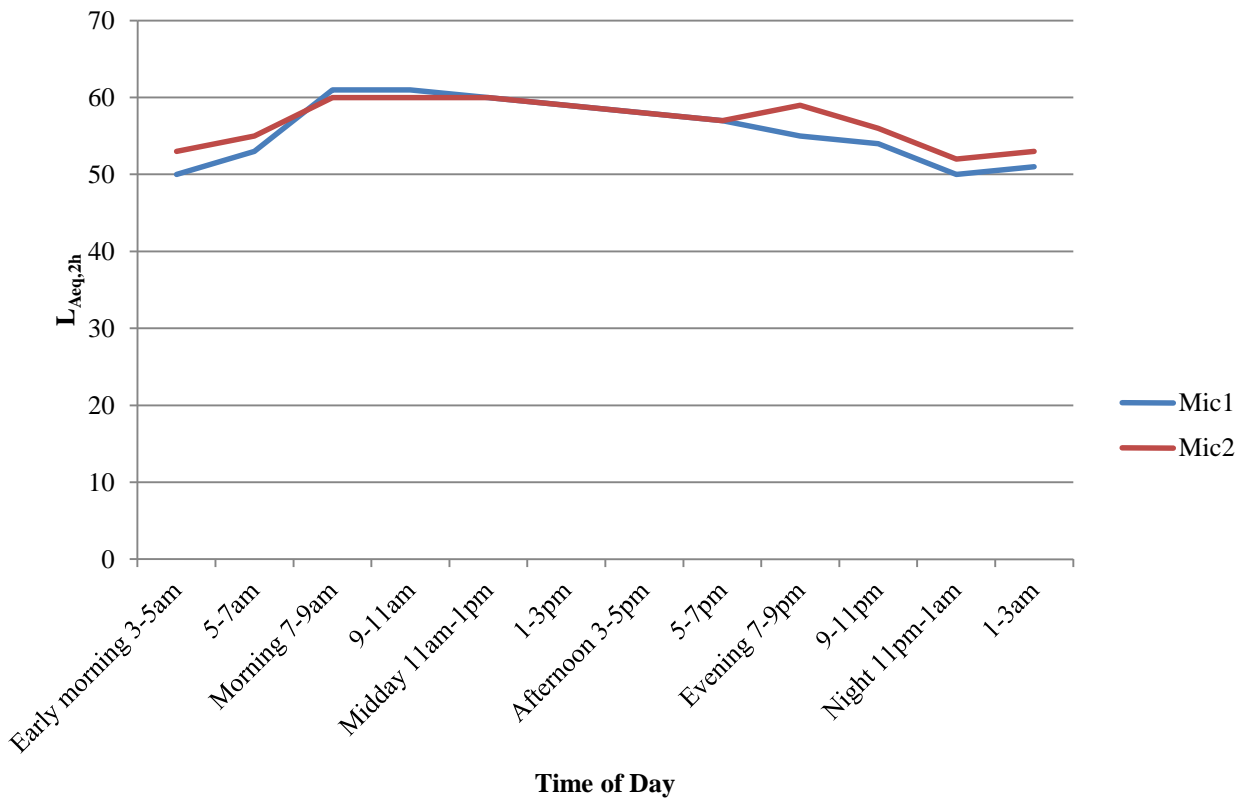


Figure 3.5. L_{Aeq} as a function of time of day for Thursday 24th September 2015.

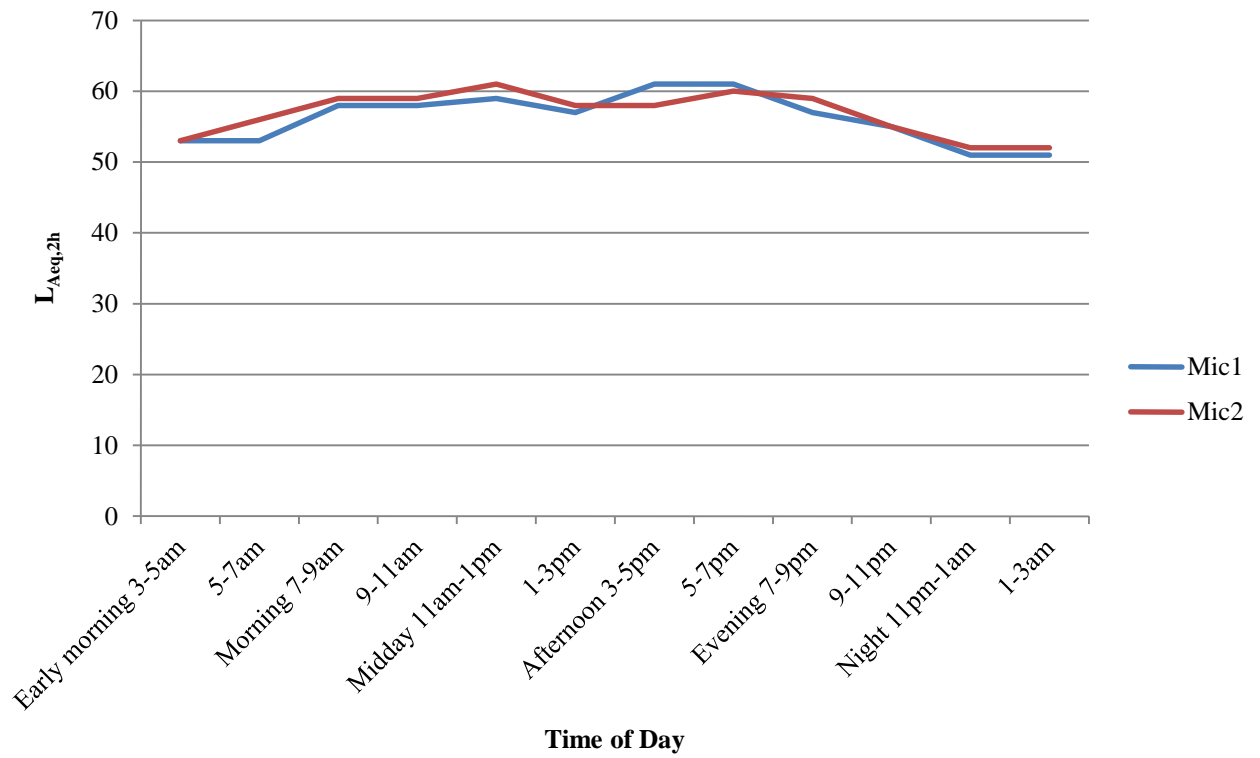


Figure 3.6. L_{Aeq} as a function of time of day for Friday 25th September 2015.

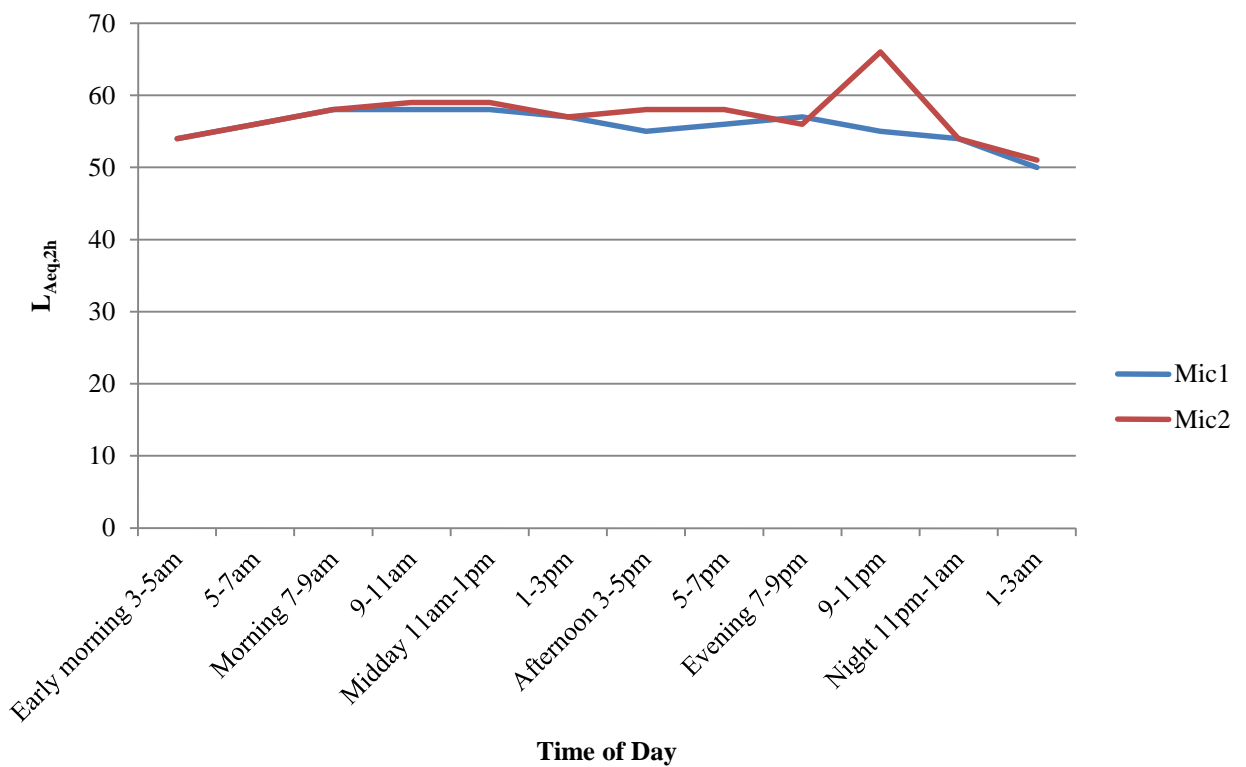


Figure 3.7. L_{Aeq} as a function of time of day for Saturday 26th September 2015.

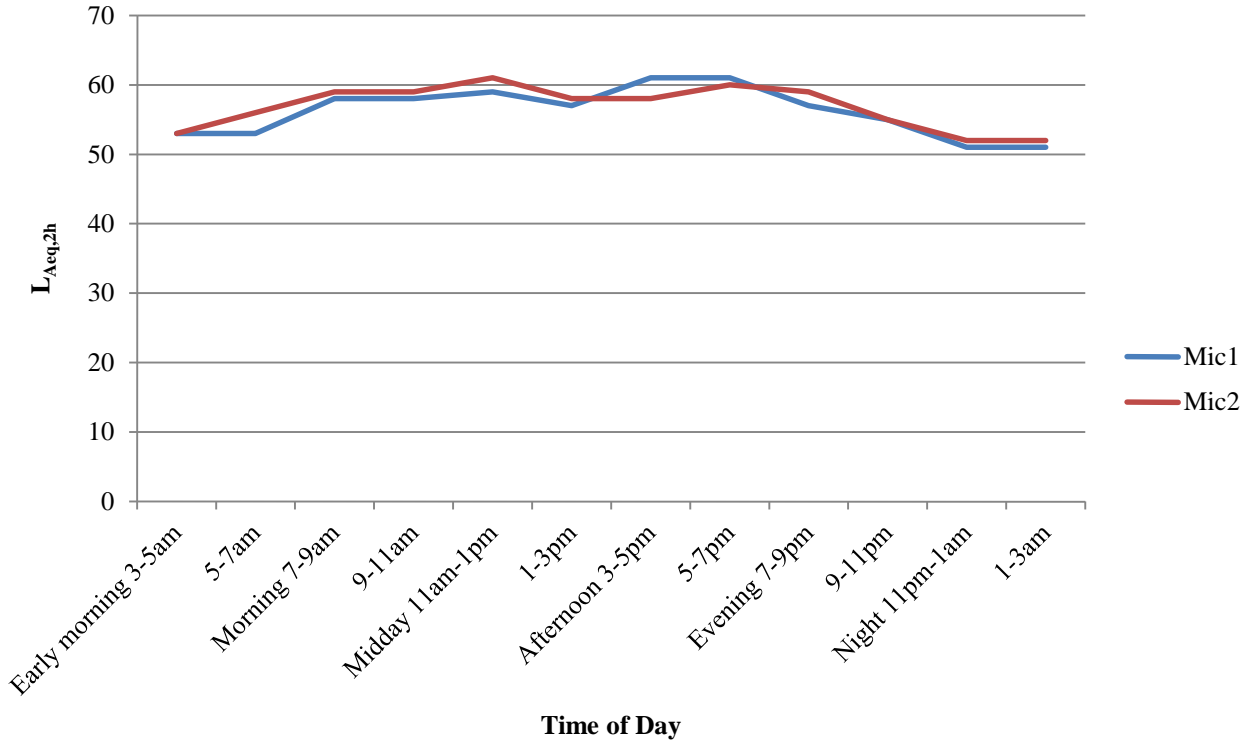


Figure 3.8. L_{Aeq} as a function of time of day for Sunday 27th September 2015.

The linear mixed-effect model test showed a significant correlation between the time of day and L_{Aeq} measured ($F(5, 155) = 122, p = <.001$). With the exception of two outliers, Monday 9:00am and Saturday 10:00pm, this correlation is visible in figures 3.2-3.8. The pairwise comparisons showed the early morning, evening and night have a significant mean difference between all times of day ($p = <.001$), however, morning, midday and afternoon were not significantly different to each other ($p = 1.00$). There were no significant correlations between the day of the week and L_{Aeq} measurements ($F(6, 155) = .51, p = .838$), nor any significant differences between the two microphones ($p = .087$). The microphone differences accounted for an estimated 33.8% of random effect L_{Aeq} variance.

3.1.2.2 L_{A10} , L_{A50} and L_{A90}

Statistical parameters of L_{A10} , L_{A50} and L_{A90} were calculated for each two-hour period on microphones one and two. L_{A10} is the noise level just exceeded 10% of the time, L_{A50} 50%, while L_{A90} 90% of the time. Figures 3.9 and 3.10 show the level of these parameters over the week of measurement for each microphone.

Linear mixed model analysis for L_{A10} showed significance with time of day ($F(5, 155) = 127.2, p = <.001$), but not day of the week ($F(6, 155) = 1.5, p = .193$). Times of day had the same significant differences as L_{Aeq} measurements, with early morning, evening and night being significant ($p = <.001$) and morning, midday and afternoon not significant ($p = 1.00$). Microphone differences were again not significant ($p = .533$), but 2.8% of random variance was attributed to this.

Analysis of L_{A50} also showed time of day was significant ($F(5, 155) = 218.7, p = <.001$), while day of the week was not ($F(5, 155) = 1.67, p = .134$). Microphone differences were not significant ($p = .489$) and contributed to 8.8% of random variance.

The parameter of L_{A90} was also significant with the time of day ($F(5, 155) = 110.2, p = <.001$) and in this case, the day of the week ($F(6, 155) = 3.0, p = .009$). Microphones were not significantly different ($p = .484$) but attributed to 11.8% of random variance.

Overall these results are very similar in being correlated with time of day; the times of day which yield the most significant difference to the others are early morning (3-7am) and night (11pm-3am). Microphones were not significantly different between any of the three parameters.

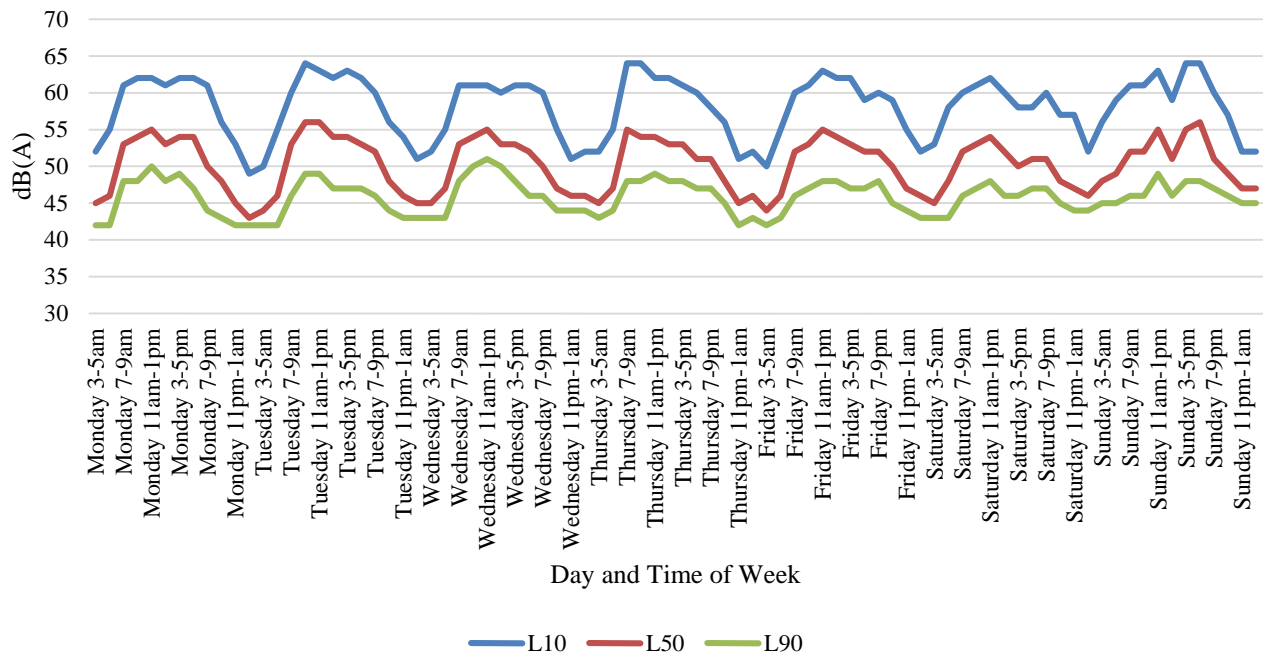


Figure 3.9. L_{A10} , L_{A50} and L_{A90} for the week of sound level measurement for microphone one.

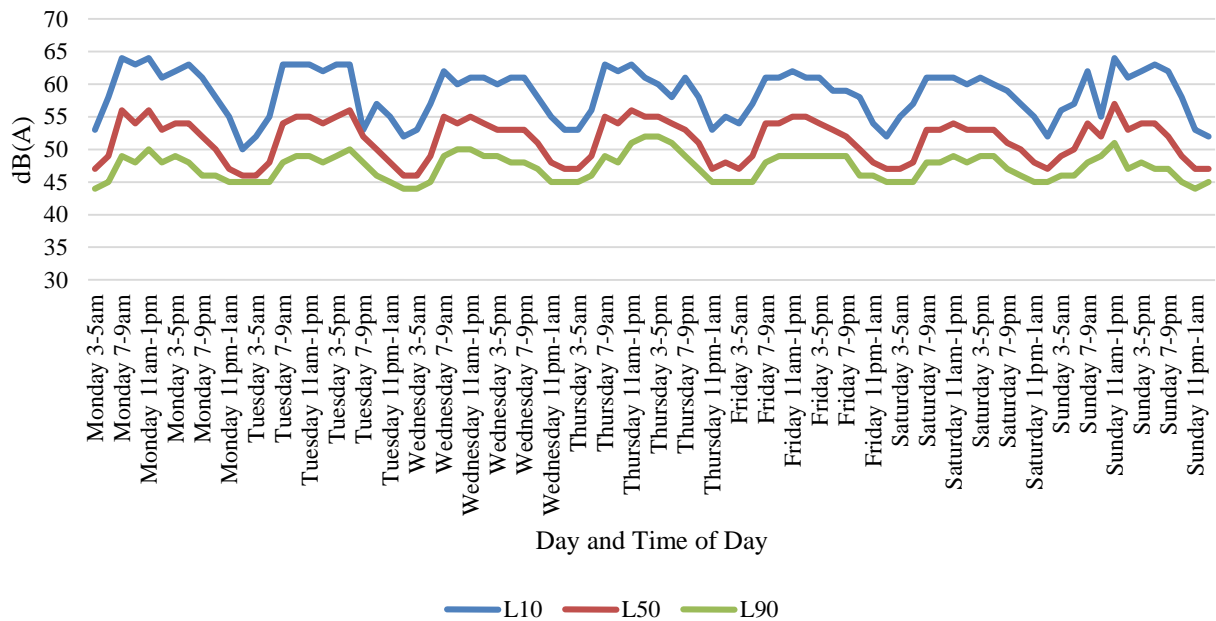


Figure 3.10. L_{A10} , L_{A50} and L_{A90} for the week of sound level measurement for microphone two.

Results for L_{AFmax} and L_{AFmin} were consistent with previous parameters. The mixed-model analysis showed that time of day was again significantly correlated with L_{AFmax} ($F(5, 155) = 5.43, p = <.001$) and not with the day of week ($F(6, 155) = .907, p = .492$). The early morning, afternoon and evening were not significantly different from any other time of day ($p = >.05$); morning and midday were only significantly different from night ($p = <.001$). Noise levels from each microphone were again not significantly different ($p = .640$) and contributed to an estimated 3.5% of random variance.

L_{AFmin} was significantly correlated with both day of the week ($F(6, 155) = 4.07, p = <.001$) and time of day ($F(5, 155) = 14.7, p = <.001$). Wednesday, Thursday and Sunday were all significantly different from each other ($p = <.001$), but the other four days were not. Again, noise levels from microphones one and two were not significant ($p = .485$) but accounted for 11.4% of random variance.

Figures 3.11 and 3.12 show the overall sound pressure level of L_{AFmax} and L_{AFmin} over the week of measurement. Consistent with elevated L_{Aeq} results for the night of Saturday 26th September, there is a visible peak around 10:00pm at microphone two.

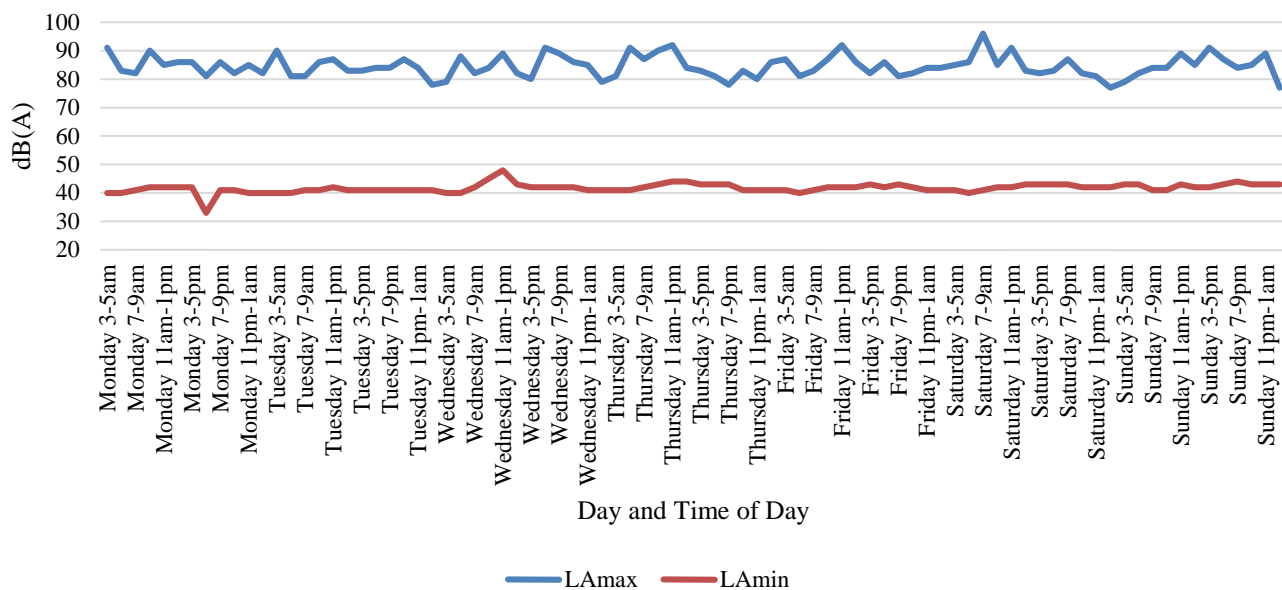


Figure 3.11. L_{AFmax} and L_{AFmin} for the week of sound level measurement with microphone one.

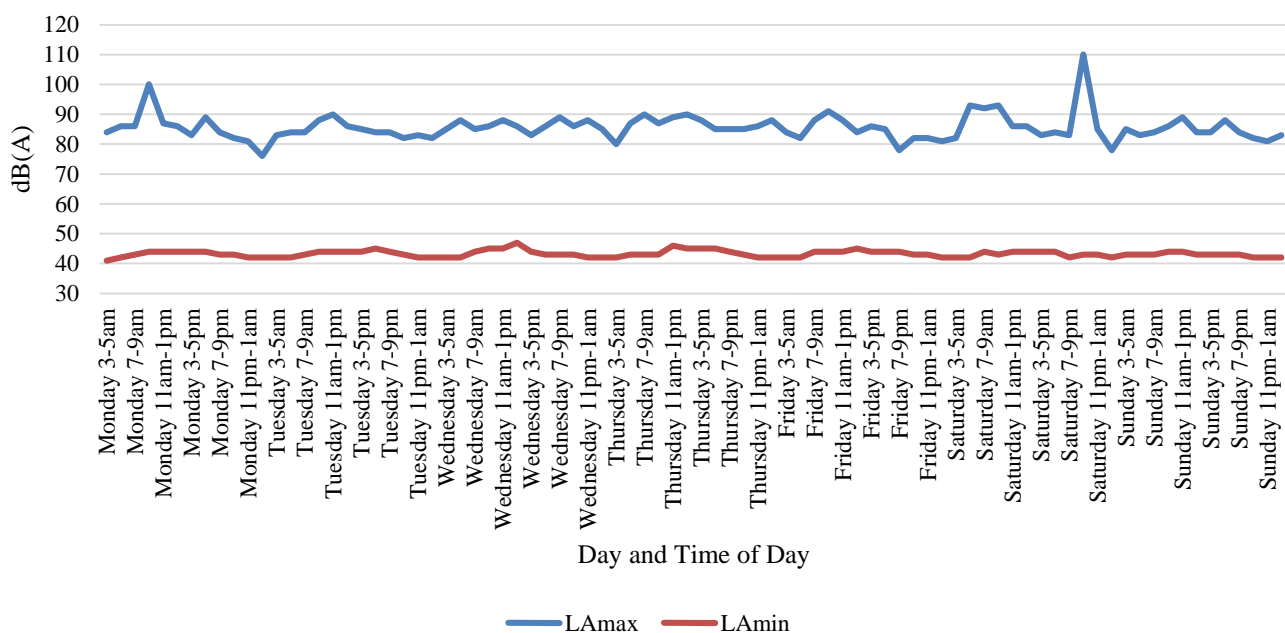


Figure 3.12. L_{AFmax} and L_{AFmin} for the week of sound level measurement with microphone two.

3.1.2.4 L_{Cpeak}

L_{Cpeak} is the highest peak level recorded in each two-hour period. Day of the week was not significant ($F(6, 155) = 1.04, p = .399$). Time of day was ($F(5, 155) = 3.95, p = .002$), however, only morning and midday had significant effects. Microphones were not a significant factor ($p = .623$) but accounted for an estimated 5.9% of random variance. The highest peak recorded was on Saturday evening around 10:00pm, which reached a level of 135dB(C), followed by Monday morning around 11:00am. The lowest peak reached for any two-hour period was 94dB(C).

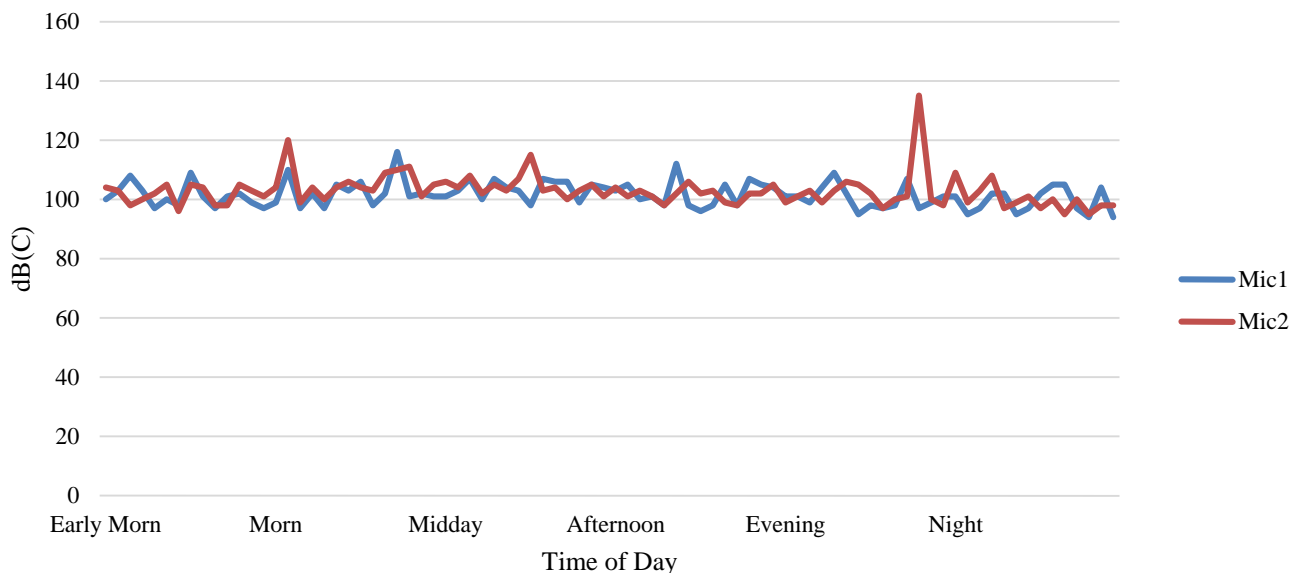


Figure 3.13. Maximum L_{Cpeak} values over times of day for the week of sound level measurement.

3.1.2.5 Number of peaks exceeding 75dB(A)

The number of noise peaks that exceeded 75dB(A) were calculated per two- hour period for each microphone. Day of the week was again not significant ($F(6, 156) = 1.54, p = .168$), while time of the day was ($F(5, 156) = 27.0, p = <.001$). Independent-rsamples t-tests were performed to compare the different microphones on number of peaks. There were significant differences between microphones one ($M = 29.9, SD = 22.7$) and two

($M = 42.5$, $SD = 21.9$) in this variable ($t(166) = -3.65$, $p = <.001$). Figures 3.14-3.20 show the various numbers of peaks above 75dB(A) over each day of the week.

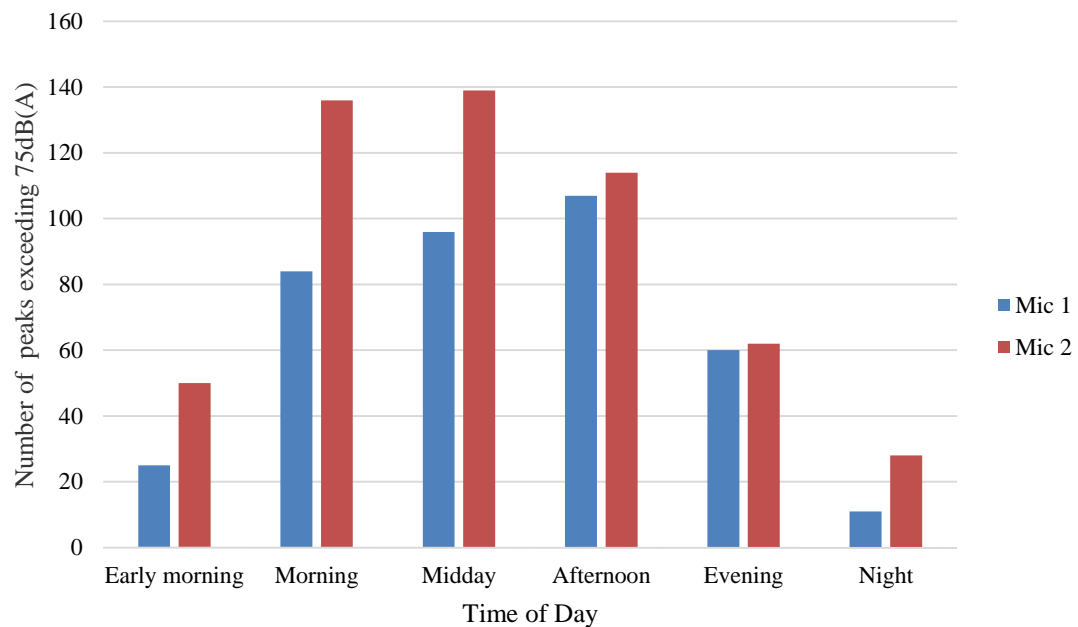


Figure 3.14. Number of peaks exceeding 75dB(A) for each time of day on Monday 21st September 2015.

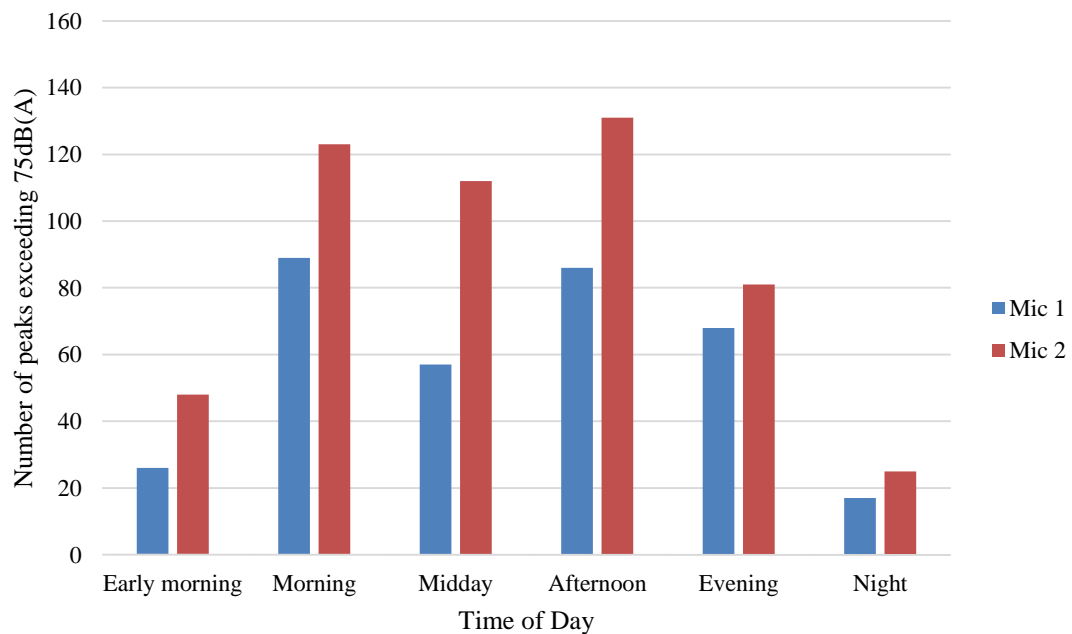


Figure 3.15. Number of peaks exceeding 75dB(A) for each time of day on Tuesday 22nd September 2015.

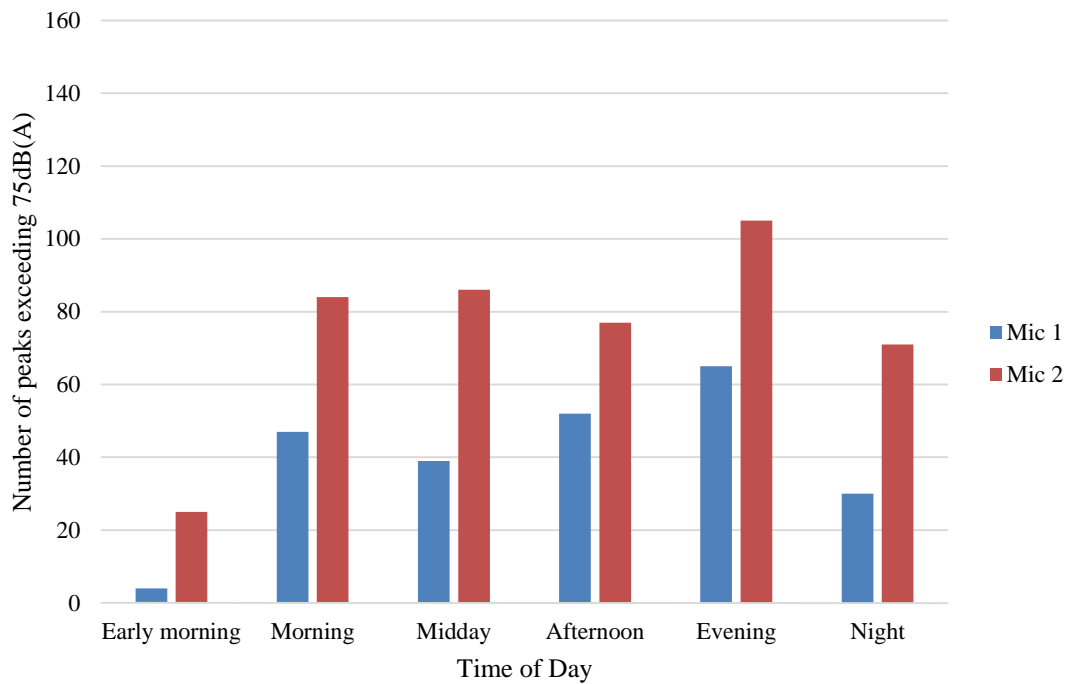


Figure 3.16. Number of peaks exceeding 75dB(A) for each time of day on Wednesday 23rd September 2015.

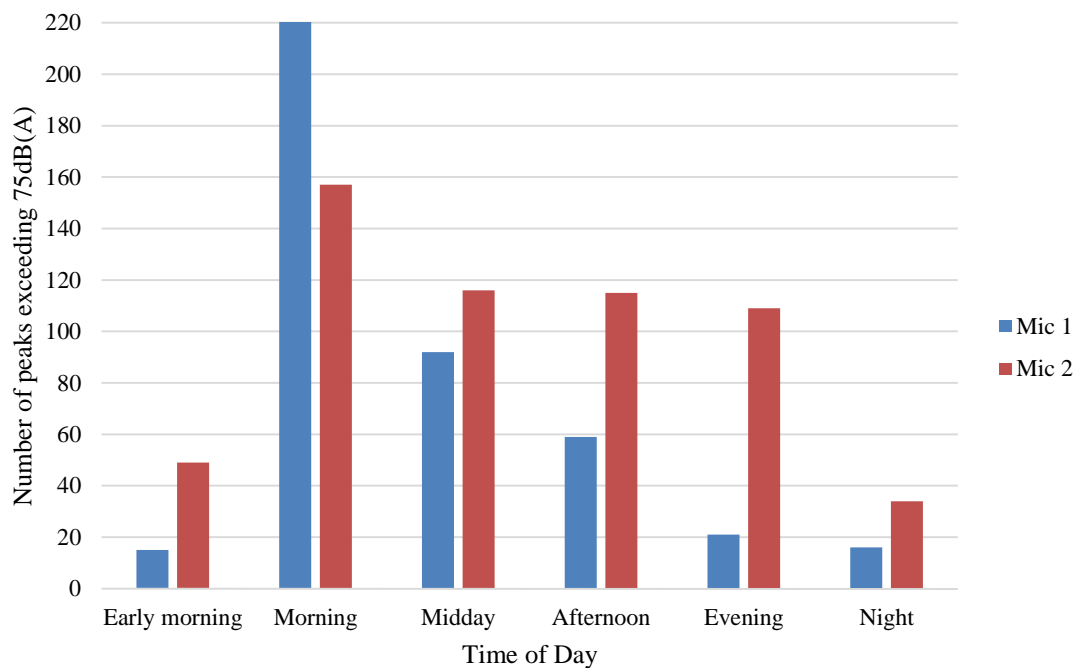


Figure 3.17. Number of peaks exceeding 75dB(A) for each time of day on Thursday 24th September 2015.

NB: Y-axis scaling differs to other charts due to the outlier in “morning” for mic 1.

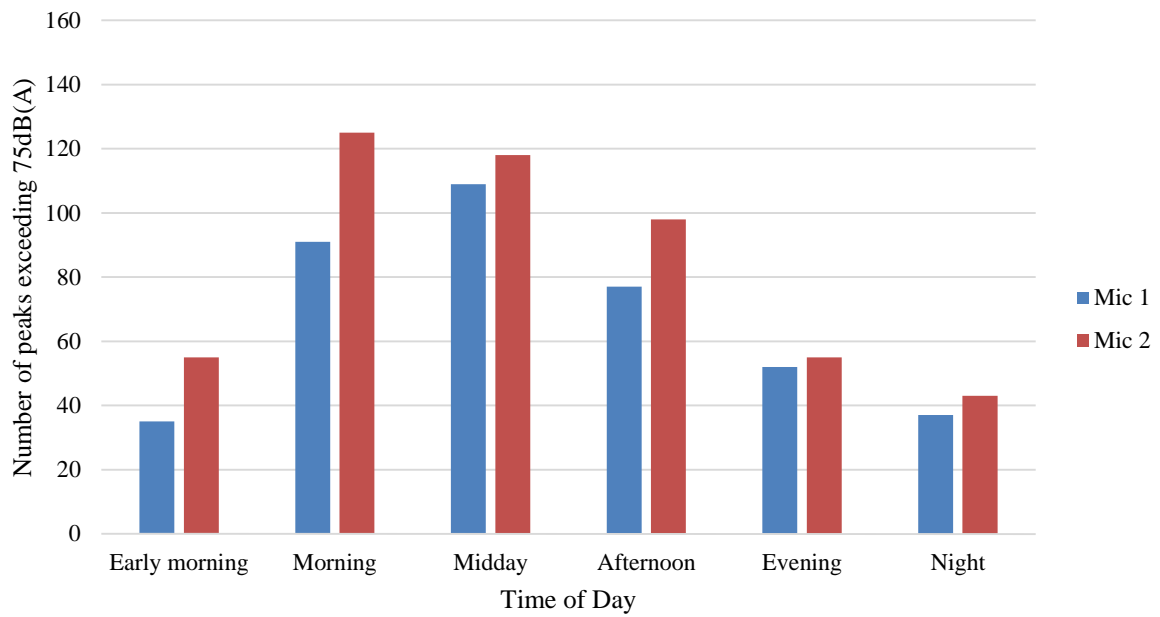


Figure 3.18. Number of peaks exceeding 75dB(A) for each time of day on Friday 25th September 2015.

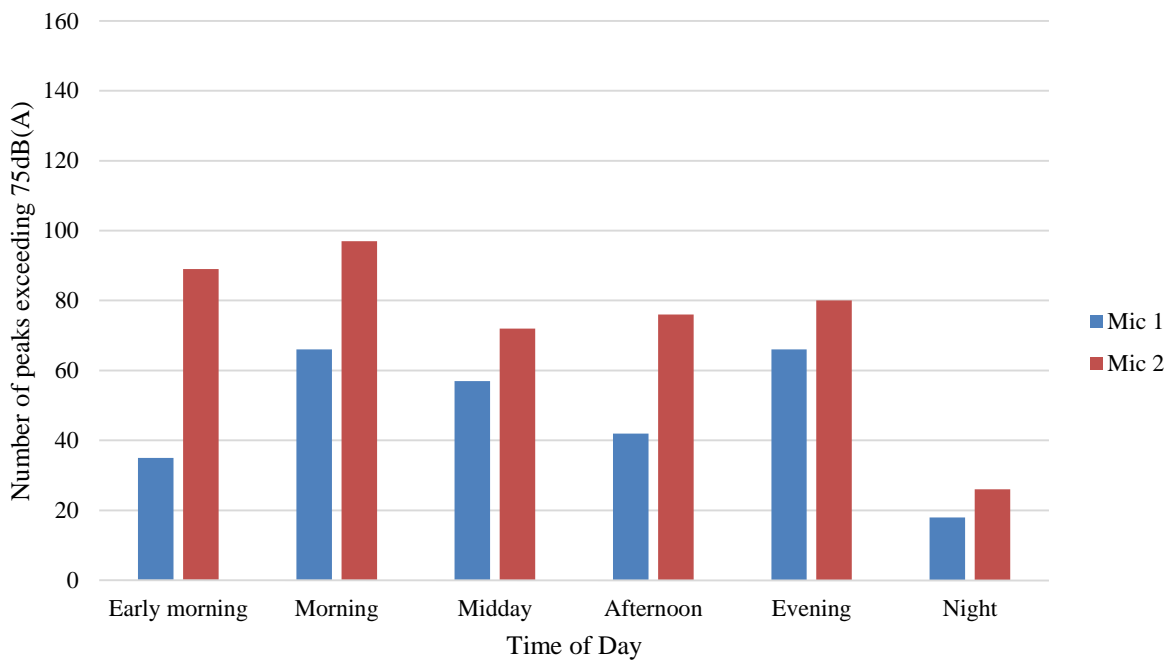


Figure 3.19. Number of peaks exceeding 75dB(A) for each time of day on Saturday 26th September 2015.

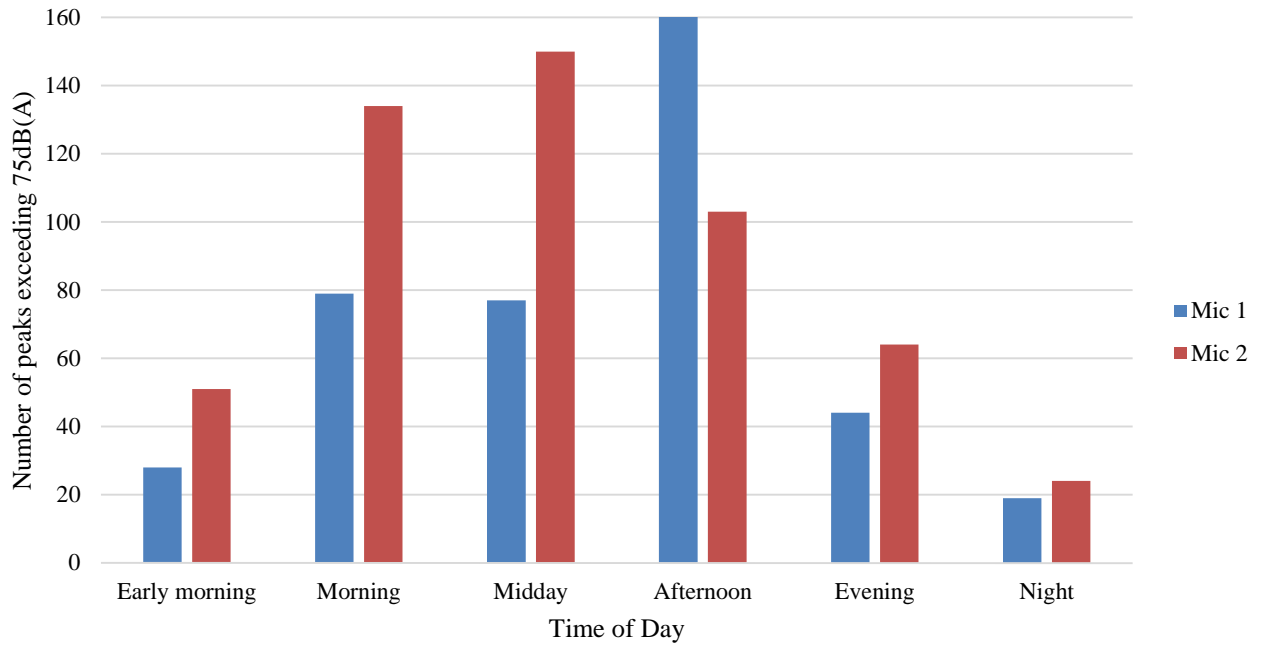


Figure 3.20. Number of peaks exceeding 75dB(A) for each time of day on Sunday 27th September 2015.

3.1.3 Spectral analysis

The frequency spectrum was analysed for eight different two-hour periods, four with a high number of peaks exceeding 75dB(A) and four with a low number (appendix 8). The main findings were that all measurements were dominated by frequencies between 500Hz-1kHz. In two-hour zones that had many peaks, those peaks tended to be between 3-4kHz, whereas quieter times had a more broadband character. Saturday night showed more high-frequency content than other times, possibly due to the 135dB(C) peak at around 10:30pm.

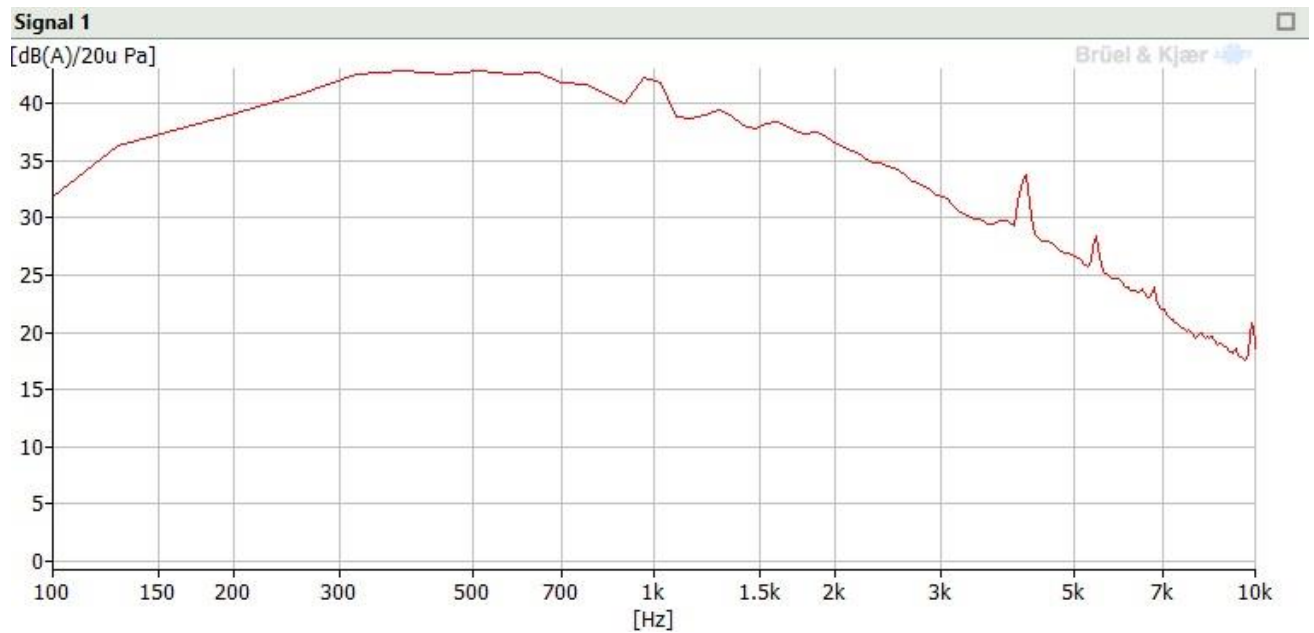


Figure 3.21. Spectral analysis of noise levels on Thursday morning, including a high number of peaks exceeding 75dB(A) from microphone two.

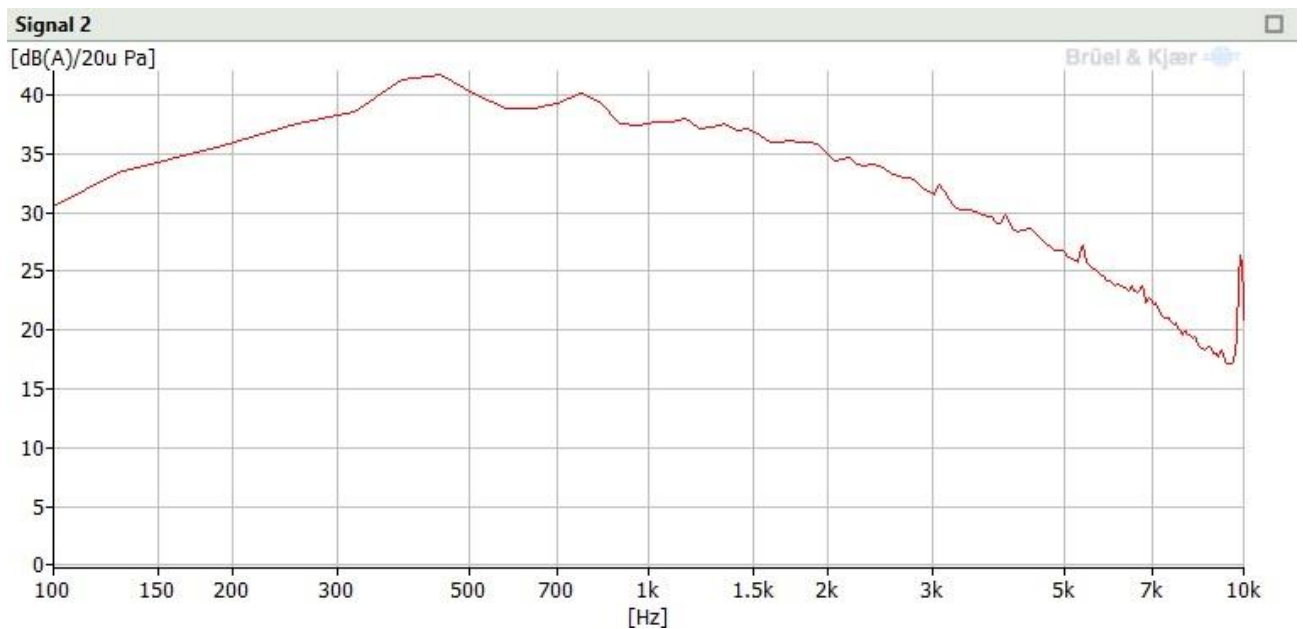


Figure 3.22. Spectral analysis of noise levels on Thursday early morning with few peaks exceeding 75dB(A) from microphone two.

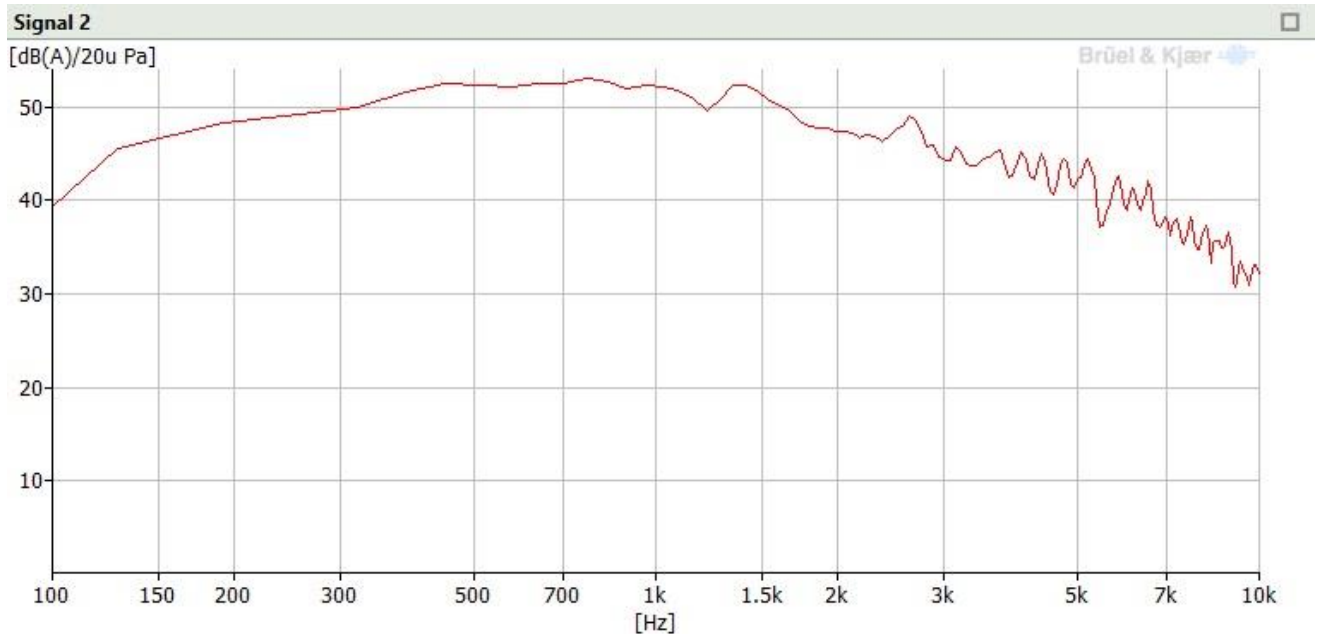


Figure 3.23. Spectral analysis of noise levels on Saturday night with microphone two, including the highest peak recorded of 135dB(C).

3.2 Surgical unit

3.2.1 Room dimensions and reverberation time

Figure 3.24 is a sketch of theatre four, showing dimensions and layout of where all orthopaedic surgery noise levels were monitored. Walls and ceilings were made from plaster board. The adjacent anaesthetic room has a separate sealed set of doors, however dimensions of this could not be obtained due to the need to maintain a sterile environment. An estimate of material absorption coefficients and reverberation times for the main surgical area of theatre four is in table 3.1 below.

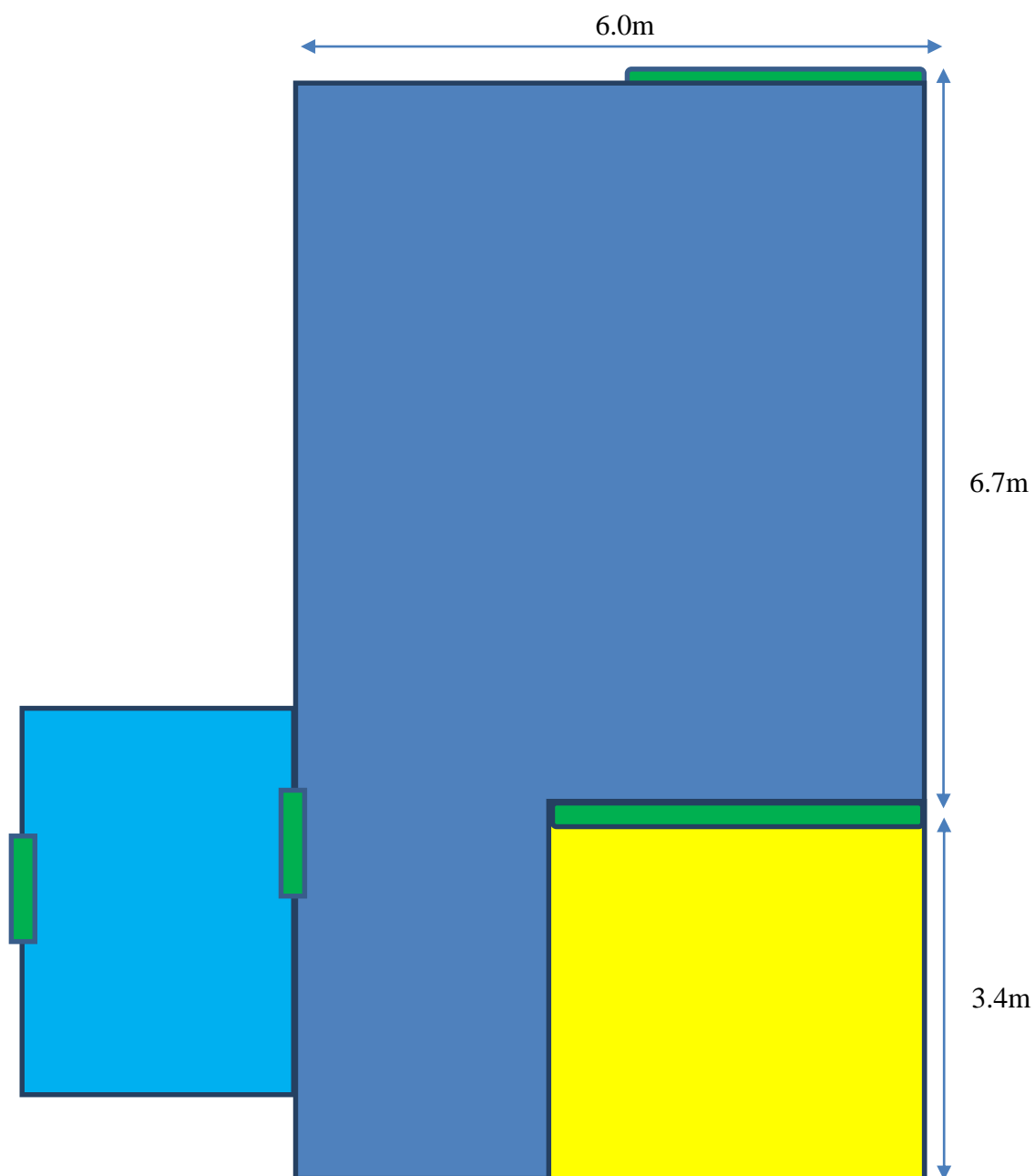


Figure 3.24. Dimensions and layout of theatre four (not to scale)

Key: Dark blue = main theatre floor, yellow = anaesthetic room, green = doors, light blue = office adjacent to theatre room (sliding door). Doors on the left and top exit to hallway corridors. Ceiling 2.8m high.

Table 3.1. Calculated reverberation times for theatre four.

Frequency		α	S	$A = S \times \alpha$	$RT = .16 \times V / A$
125Hz	Walls	.02	71.12m ²	1.42	6s
	Floor	.02	40.0m ²	.08	
	Ceiling	.02	40.0m ²	.08	
			Total: 151.12m²	Total: 3.02	
250Hz	Walls	.03	71.12m ²	2.13	4s
	Floor	.03	40.0m ²	1.20	
	Ceiling	.03	40.0m ²	1.20	
			Total: 151.12m²	Total: 4.53	
500Hz	Walls	.03	71.12m ²	2.13	3.4s
	Floor	.04	40.0m ²	1.60	
	Ceiling	.04	40.0m ²	1.60	
			Total: 151.12m²	Total: 5.33	
1000Hz	Walls	.03	71.12m ²	2.10	3s
	Floor	.05	40.0m ²	2.00	
	Ceiling	.05	40.0m ²	2.00	
			Total: 151.12m²	Total: 6.10	
2000Hz	Walls	.03	71.12m ²	2.13	3.4s
	Floor	.04	40.0m ²	1.60	
	Ceiling	.04	40.0m ²	1.60	
			Total: 151.12m²	Total: 5.33	
4000Hz	Walls	.02	71.12m ²	1.42	4.7s
	Floor	.03	40.0m ²	1.20	
	Ceiling	.03	40.0m ²	1.20	
			Total: 151.12m²	Total: 3.82	

NB: V (room volume) = 112.50m³; α = absorption coefficient; S = area of individual surface. RT60 figures rounded to nearest decimal place.

3.2.2 Noise measurements

Noise levels during surgical procedures were measured with both a dosimeter and a sound-level meter. Table 3.2 displays the results for each surgery type below tested with the sound level meter. Results from the dosimeter were very similar to those below, with slightly elevated L_{Cpeak} levels due to the microphone being closer to the noise source.

Table 3.2. Noise levels in surgeries, their statistical parameters and notes on subjective noise sources.

Surgery	L_{Aeq}	L_{Amax}	L_{Amin}	L_{Cpeak}	Notes
Radius 1	74dB(A)	98dB(A)	55dB(A)	116dB(C)	Music medium level, peaks = dropping tools, hammering metal rod into arm, moving X-ray machine away
Radius 2	72dB(A)	88dB(A)	54dB(A)	121dB(C)	
Ankle 1	70dB(A)	86dB(A)	52dB(A)	111dB(C)	Music on, peaks = dropping tools, hammering into ankle, pneumatic drill suction
Ankle 2	61.8dB(A)	84dB(A)	44dB(A)	103dB(C)	
Hip review 1	70dB(A)	85dB(A)	51dB(A)	110dB(C)	Not subjectively loud overall, except when mallet hitting bone/prosthetic
Hip review 2	67dB(A)	92dB(A)	48dB(A)	115.9dB(C)	
Cardiac 1	66dB(A)	87dB(A)	51dB(A)	116dB(C)	Not subjectively loud, only suction air supply
Cardiac 2	62dB(A)	85dB(A)	48dB(A)	105dB(C)	

3.3 Staff surveys

A total of 41 surveys were completed and returned. This was a lower number than expected due to the distribution of ~200 surveys in 120 anaesthetic technicians' mail boxes and the remainder being left in the staff room of the ICU department. Of this 41, four (9.8%) were nurses, one was in the clinical team (2.4%), two were in the surgical unit (4.9%), 33 were in the anaesthetic team (80.5%) and one was an occupational therapist (2.4%).

There were no respondents in the under 20 age group. 9.8% of respondents were between 21-30 years old, 24.4% were between 31-40 and 46.3% were over 50 years old. Of all respondents, 4.9% had less than 1 years' experience, 2.4% had 1-3 years', 7.3% had between 3-6 years', 4.9% between 6-10 years' and 80.5% had over 10 years' experience in the New Zealand health sector. There was no question determining gender.

There were twelve questions aimed at noise in the workplace, with table 3.3 below showing the distributions of each question. There were no questions left blank. The only significant correlations determined by using Spearman's rank correlations were with age and "the level of noise at work does not bother me" ($p = .049$) and "my friends or family think I have a hearing problem" ($p = .035$). Years' experience and department/medical team were not significantly correlated with any questions, however, this study would need equal numbers of participants in each group and more participants in general to be a conclusive estimate of variance.

Table 3.3. Table of staff questionnaire responses determined by descriptive statistics.

Question	Strongly Agree	Agree	Disagree	Strongly Disagree	Don't know
Level of noise at work does <i>not</i> bother me	0%	31.7%	39.0%	29.3%	0%
It would make <i>no</i> difference to my hearing if work was quieter	2.4%	24.4	39.0%	19.5%	14.6%
I would feel better if my workplace was less noisy	22.0%	51.2%	26.8%	0%	0%
My friends/family think I have a hearing problem	2.4%	34.1%	24.4%	29.3%	9.8%
I <i>cannot</i> reduce noise in the workplace	7.3%	34.1%	48.8%	9.8%	0%
There is <i>no</i> route to making complains about work noise	0%	31.7%	46.3%	2.4%	19.5%
I know when a noise is loud enough to damage my hearing	2.4%	26.8%	51.2%	2.4%	17.1%
Noise only affects hearing in people with sensitive ears	0%	2.4%	46.3%	51.2%	0%
My colleagues do <i>not</i> worry about noise	2.4%	26.8%	48.8%	2.4%	19.5%
I struggle carrying on a conversation because of background noise	9.8%	46.3%	41.5%	2.4%	0%
Noise is <i>sometimes</i> so loud, concentrating is difficult	14.6%	63.4%	17.1%	4.9%	0%
Noise is <i>always</i> so loud, concentrating is difficult	2.4%	7.3%	61.0%	29.3%	0%

At the bottom of each survey there was space for comments that 12 out of 41 participants used. Comments were:

1. “Noise is often so loud it is distracting and stressful, generally loud chatter that is irrelevant and a safety hazard.”
2. “Unit very noisy due to alarms/multiple medical teams/current renovations of hospital site.”

3. “Noise levels are very variable, occasionally very loud with some surgical tools. It is most noticeable when putting people to sleep, nurses talking, opening instrument packaging – this is disrespectful to patients but the actual level of noise is okay.”
4. “The noise from construction is the worst, we ‘jump’ at the drilling/banging.”
5. “If noise is too loud I take steps to reduce it, i.e turn radio off/call others to quieten down as appropriate. I suspect my hearing is beginning to get impaired but unsure if this is an age-related norm.”
6. “Ongoing building noise increases noise pollution.”
7. “Things that bother me the most are often high-pitched constant background noise from machines like suction. I also find myself turning up my monitor to overcome the background noise so that I can hear.”
8. “Some theatres are noisier than others – e.g orthopaedic theatres would have a lot of banging (hammering) noise, where plastics might be quieter. There is construction work being done in Christchurch and there may be temporarily more noise than other times.”
9. “In regards to Q13,” (‘Noise is sometimes so loud I find it hard to concentrate’), “with post-earthquake repairs it has on occasions been too noisy to work/concentrate, and for the patients I’ve had to get the men to stop so that we can continue with the surgical list. But otherwise it has not been too loud to concentrate.”
10. “Constant alarms are the most irritating noise.”

The two other comments were about their current hearing loss and hearing aids.

Chapter Four: Discussion

4.1 ICU

4.1.1 Reverberation and attenuation

Hard non-porous materials are generally less sound-absorbent than soft porous materials, creating longer reverberation times (Gastmeier & Aitken, 1999). The interior of Christchurch hospital's ICU is lined with hard plasterboard and a linoleum floor, producing a very reverberant field and potentially reducing speech intelligibility. It is understood that low-frequency noise is harder to absorb (Seep, et al, 2000), yet according to previous research, it is more disturbing than higher-frequency noise and can result in decreased sleep, increased cardiovascular arousals and higher instances of rehospitalisation (Ryherd, et al, 2011). In Christchurch Hospital's ICU, the absence of sound-absorbing materials may extend patient recovery time due to a lack of rest or interrupted sleep and they may suffer delayed wound healing (McCarthy, et al, 1991). There appear to be opportunities to install sound absorption systems such as those being developed by the University of Canterbury's Acoustics Research Group. Hagerman, et al, (2005) report the installation of these systems may reduce reverberation time and increase speech intelligibility.

4.1.2 Noise levels

4.1.2.1 L_{Aeq}

According to the WHO (Berglund, et al, 1999), patients in the ICU should be given special attention due to their immediate health concerns (Berglund, et al, 1999). The noise levels measured in the Christchurch ICU greatly exceed the levels recommended by the WHO. The L_{Aeq} recorded during the day it was between 55 and

63dB(A) compared to the recommended 35dB(A), while overnight was between 48 and 55dB(A) compared with the recommended level of 30dB(A). These elevated noise levels may be causing patients adverse psychological and physiological effects such as stress, annoyance, fatigue, insomnia, adrenaline increases, heightened blood pressure and heart rate and increased hospital stays (Hsu, et al, 2010; Stansfeld & Matheson, 2003). These levels may also be affecting staff members' concentration, stress levels and speech intelligibility of instructions or information. However, these effects were not able to be assessed in the present work.

Overseas studies reported in section 1.5.4 all exceeded the WHO (Berglund, et al, 1999) guidelines. Busch-Vishniac, et al, (2005) found L_{Aeq} for five different hospital locations were between 50 and 60dB(A); Darbyshire and Young (2013) found L_{Aeq} over five ICUs in the UK were above 45dB(A); Hsu, et al (2010) found an L_{Aeq} of between 59 to 60dB(A); MacKenzie and Galbrun (2007) measured L_{Aeq} in two ICUs in the UK, finding 54 to 59dB(A); Salandin, Arnold and Kornadt (2011) found L_{Aeq} to be 53 to 59dB(A) in Germany and Xie, Deng and Kang (2013) found China's L_{Aeq} to be between 57 and 64dB(A). Christchurch Hospital's ICU L_{Aeq} of 55 to 63dB(A) during the day is very similar to levels found in international studies.

4.1.2.2 L_{AFmax} , L_{AFmin} , L_{A10} , L_{A50} and L_{A90}

L_{AFmax} levels were between 80 and 90dB(A) for most times of the day, which is around the sound level of a passing truck or a lawn mower. These levels, regardless of how long their exposure time is, have the potential to wake patients from sleep, mask other important sounds and disrupt the activities of staff. In a comment from one survey participant (section 3.3), it was stated that he/she turns up their monitor to overcome the background noise. This may overcome the background noise for that particular person

and contribute to the overall level of noise. This then elevates the level of someone else's "background noise", perhaps in turn increasing their alarms too. L_{AFmin} levels measured were all above 40dB(A) except for one two-hour period in the afternoon on Monday. This suggests that for both microphone placements, noise levels were never as quiet as the recommended 35dB(A) during a day-time period. This is similar to having at least light traffic or a quiet conversation continuously all day and night.

Hsu, et al, (2010) found L_{Amax} levels of 77 to 81dB(A) in a Taiwanese ICU; MacKenzie and Galbrun found L_{Amax} a UK hospital was between 71 and 73dB(A) and Sen, Weitao and Zheng (2013) found L_{Amax} in China was between 85 and 95dB(A). Christchurch Hospital L_{Amax} levels were very similar to these international findings, with 80 to 90dB(A) recorded. Hsu, et al (2010) found L_{Amin} levels of 53 to 55dB(A) and Sen, Waitao and Zheng (2013) report 51 to 67dB(A), higher than Christchurch Hospital levels of 38 to 50dB(A).

Statistical parameters of L_{A10} , L_{A50} and L_{A90} show the fluctuation in noise levels with time of the day. For both microphone placements, L_{A90} shows that noise levels are at least 5 to 10dB(A) above the WHO recommended levels (Berglund, et al, 1999) 90% of the time. L_{A10} shows that levels were above 60dB(A) during the day and 50dB(A) at night over 10% of the time noise levels were measured.

4.1.2.3 Peaks

Peaks in noise contributed to the averaged noise levels measured in Christchurch Hospital. From the L_{Cpeak} readings, we know that there was at least one peak above 90dB(C) every two hours, and usually many more than one. This is subjectively as loud as a belt sander or lawn mower.

Two peaks in particular, both measured by microphone two, reached 120dB(C) and 135dB(C) on Monday morning and Saturday night respectively. This is analogous to a sudden thunder clap or air raid siren. From the position of the ICU microphones on the curtain railings, we know that at least the 135dB(C) peak may have exceeded the 140dB occupational limit at the true source of the noise. This may have been near a patient or staff member's head, therefore enhancing the possibility of a noise-induced hearing loss. Henderson, et al, (1990) reports that any impulse sounds above 119dB (unweighted) may increase a temporary hearing threshold shift (TTS) by around 5dB per additional dB of noise. It is unknown what caused these peak levels, however, the 135dB(C) peak on Saturday night has predominantly more high-frequency weight in the spectrum than other periods, suggesting this could have been caused by a metal trolley crashing or a very loud alarm. Even though no peaks exceeded the Health and Safety in Employment Regulations (Department of Labour, 1995), peaks this high are sufficient to disturb all patients and staff, causing stress and concern (Berglund, et al, 2004; Ryherd, et al, 2011). It is understood that peaks may cause more disturbance than continuous noise (Berglund, et al, 2004), increase the time it takes for a patient to fall asleep and prematurely awaken patients (Öhrström, 1993). Peaks in the current study may also have affected staff members' routines, causing a lack of concentration and potential lapse in patient care.

Peaks in overseas studies were variable depending on the environment. Peak levels in previous studies conducted in ICUs only show levels that are comparable to Christchurch Hospital, however most of these were measured using an A-weighting filter. Christensen (2007) reports peaks reached 80dB(A), Darbyshire and Young (2013) found peaks above 85dB(A) for 1 to 2 minutes per hour and Salandin, et al, (2011) report alarm peaks were approximately 90dB(A).

The number of peaks above 75dB(A) were counted to get a more thorough idea of peaks and troughs in the data. Upon analysis of this, it is clear that there are many causes of loud peaks, however, there is a strong correlation with the time of day and number of these. Preliminary sound level measurements (appendix 2) with observation showed that peaks were caused by metal bins, doors slamming, loud speech, drawers shutting and alarms. This gives a good indication as to how behaviour modification may help in reducing noise levels (section 4.4.1).

Above all other parameters, the number of peaks was significantly correlated with perceptions of noise annoyance in overseas studies (Ryherd, et al, 2011). However, only one other study reported peaks with an occurrence rate. Salandin, et al, (2011) found an average of six peaks per hour exceeding 70dB(A). This is a very low rate compared to Christchurch Hospital levels, where sometimes there were up to 100 peaks above 75dB(A) per hour measured at one of the microphone positions.

Speaking to medical staff while in the ICU allowed some insight to their routine. Nursing staff may alter each patient's alarms to the nurse's individual liking. For example, if one nurse prefers having more frequent or louder alarms for their patients, they have full control over this. Elevating alarm levels to the staff member's liking may affect everyone else around them, including the well-being of the patients themselves. Berglund, et al, (2004) found that impulse sounds like sudden alarms had a larger negative effect on people than a continuous sound of the same sound level, therefore the suppression of peaks is of utmost importance. Alarms are also mostly pure-tone sounds, which can cause a larger TTS (Kryter, 1970) and cause more annoyance than broader spectrum sounds (Landström, et al, 1995). Observation of alarm management in Christchurch ICU showed that most nurses quickly check the patient's status and press a button to stop the alarm. As Atzema, et al, (2006) reported, around 99% of alarms they

studied were false and required no action to the patient. If most alarms are around 70dB(A) (Topf, 2000) but require no action, it is recommended for patient safety and staff accuracy that these alarms be set to narrower parameters to prevent them becoming “background noise” rather than an alarm.

4.1.2.4 Spectral analysis

The fast-fourier transform spectral analysis shows most sound recorded in the ICU centred around 500Hz-1kHz. Much of human speech lies within these frequencies, and the sound level of most conversation is around 50-60dB. Low-frequency noise under 200Hz is often attributed to fan and electrical noise, which was apparent in the ceiling air conditioning registers and electrical monitors in the Christchurch ICU. Although the low-frequency noise was at a low level, these frequencies can cause annoyance when constantly present, especially for those trying to sleep and can be perceived as unwanted noise at a much lower level than for higher frequencies (Kryter, 1970). Moderate level low-frequency noise also has a larger effect on speech intelligibility than high-frequency noise (Kryter, 1970). This phenomenon is most easily seen in group situations, where people struggle more than normal to discern what is being said. This is particularly important for patients and families in hospital as they seek to understand what is happening. With significant background noise, both staff and patients may misunderstand illness implications or instructions.

4.1.2.5 Extraneous factors

a) Staff speech

During the preliminary measurement period it was noted that most continuous noise was due to conversation, however this was usually directly related to a patient. If

the level of staff speech was reduced noise levels would be significantly lower, but this might affect the easy, positive atmosphere. Staff chatter was always friendly towards patients and myself throughout measurement. It would be of benefit to keep the amount of casual staff chatter, but reduce the volume so that only adjacent patients could hear the conversation.

b) Construction noise

Berglund, et al, (1996) states construction noise carries loud low-frequency components. It is unknown how much contribution the ICU building extension work had on overall noise levels as this was an ongoing factor throughout preliminary sound level meter measurements and the week's dual microphone Pulse measurements. However, some staff members complained that construction noise was their primary concern at present. Five out of 12 people who responded in the "comments" section of the staff surveys (section 3.3) mentioned construction noise, with one respondent adding it to a list of noise sources, one stating it was the "worst" noise, one saying it increases noise pollution, one offering it as the reason for temporarily elevated noise levels and one stating that the only time noise has been too loud to concentrate was with the post-earthquake repairs. Fife and Rappaport (1976) found that construction noise outside patients' windows increased their length of recovery and chance of being rehospitallised (section 1.5.3). With comments of staff members saying construction noise can make them "jump", it may be a contributor to an increased number of peaks within time periods, however, this cannot be proven as yet.

c) Microphones one and two

There were significantly more peaks measured by microphone two than microphone one. Microphone two was further away from the construction site, but was in the direct intersection of the two main floor paths of the ICU and also outside the administration office. The blood transfusion alarm was also positioned above bed five (microphone two). This microphone may also have picked up peaks coming from both sides of the 'L' shaped ICU bedding arrangement, staff conversation and administration's phones, faxes and other electronic devices. New staff teams also arrive through the doors near microphone two, creating extra noise from conversation and wheeling beds or other equipment such as radiography machines.

The placement of the two microphones may have affected data. Ideally, the microphones would be at patient head level, far enough away from the wall to eliminate interference. However, this could not eventuate due to patient equipment (section 2.3.1). The microphones being placed on curtain rails adds distance and height to the recorded sound level measurement. Other factors could be additional noise from curtain hooks/rungs. This noise may be louder than perceived by staff or patients due to the proximity of the hooks to the microphones.

d) Other factors

Staff awareness and change in behaviour may have affected noise levels. If staff were aware of microphone placement and the aims of study, they may have altered their behaviour to reflect more positively. The WHO (Berglund, et al, 1999) and the US EPA (1974) recommend any noise measurements be recorded under normal circumstances. It is unknown if this had an effect on the current study, although it was impressed on the staff that this study should not affect their normal routines.

With measurement being taken over a one-week period, physical observation was unable to be completed. If observation or camera recording was able to be done, there would be much less guess-work as to the source of peaks and spectral data.

4.2 Surgical unit

4.2.1 Reverberation and attenuation

Theatre four was lined with plasterboard. The reverberation times (RT60) of this theatre at different frequencies were all estimated to be 2.95 seconds or longer. RT60 longer than 3.50s may affect speech intelligibility (Gastmeier & Aitken, 1999). Frequency bands with an estimated RT60 longer than 3.50s were 125Hz, 250Hz and 4kHz, therefore they may be highly reverberant and “echo”. Hagerman, et al (2005) report acoustic treatment can reduce RT60 and increase speech intelligibility. Any acoustic treatment for Christchurch Hospital needs to provide absorption for a sterile environment. Aforementioned, development of acoustic treatment by the University of Canterbury’s Acoustics Research Group is currently being investigated.

4.2.2 Noise levels

Noise levels in surgeries did not exceed the Health and Safety in Employment Regulations (Department of Labour, 1995) criteria of 85dB(A) $L_{Aeq,8h}$ or 140dB for noise peaks. However, peak levels were all above 100dB(C), which is still a level high enough to damage the ear if continuously present. The effect of these peaks on patients should also be considered, and ear plugs should be provided to any surgery patients prior to anaesthetic induction (Nott & West, 2003).

Even if these L_{Aeq} levels of 60-75dB(A) are not high enough to be considered damaging, exposure to these over a shift of hospital staff (usually longer than the standard

eight-hour working period) can cause fatigue, stress and a loss of concentration (Murthy, et al, 1995; Stansfeld & Matheson, 2003) and a higher blood pressure (Lang, et al, 1992). The WHO (Berglund, et al, 1999) suggests speech is fairly intelligible in noise levels of 45dB(A), but at 65dB(A) more vocal effort must be used to achieve reasonable intelligibility, therefore further increasing noise levels and fatigue for theatre staff.

Overseas studies report similar levels of noise during surgery as found in Christchurch Hospital. Fitzgerald and O'Donnell (2012) found a mean noise level of 63dB(A) and an L_{Amax} of 93dB(A) in orthopaedic surgeries in the UK; Tsaio, Efthymiatis and Katostaras (2007) found a maximum L_{Aeq} of 72dB(A), L_{A99} of 57dB(A) and peaks between 99 and 106dB(A) in Greek hospitals and Willett (1991) found all surgical tools created noise above 90dB(A). Christchurch hospital surgery L_{Aeq} were between 61 and 74dB(A) with peaks between 103 and 121dB(C) caused by hammers and mallets. Previous studies conducted in the North Island of New Zealand by Love (2003) and Liddell (2008) showed L_{Aeq} levels of 68-85dB(A), which are slightly higher than levels found at Christchurch Hospital, however, these North Island studies measured noise in full hip and knee replacement surgeries. Christchurch Hospital does not perform these full surgeries, only reviews. Full replacements require longer times with surgical equipment and are completed at Burwood Hospital, also in Christchurch. The higher noise levels are mostly due to the tools used in orthopaedics such as hammers, saws and drills.

Ginsberg, et al, (2013) found that anaesthetic technicians suffer from the most noise in theatre. They report all L_{Amax} noise levels during surgery are above 80dB(A), but during anaesthetic induction these were above 90dB(A). Due to sterility issues, noise levels were not able to be measured during the anaesthetic induction at Christchurch Hospital, therefore no correlation can be made with overseas studies in regards to stages

of surgery. Anaesthetic technicians accounted for 80% of the staff surveys that were returned. There is a large disproportion between these survey responses and a lack of data from this phase of surgery.

Music was played in at least half the surgeries observed. Overseas studies reported music can be both a negative and positive background noise for staff (Hawksworth, et al, 1997; Ullman, et al, 2008). More research needs to be done in this field to have a definitive answer, however, age of staff member could be a factor. A more recent study by Way, et al, (2013) showed that normal-hearing surgeons performed worse in background music on speech-in-noise testing. Through observing Christchurch Hospital surgeries, those with music playing were often led by younger surgeons, indicating there may be an age discrepancy in New Zealand too. More surgeries would need to be monitored for this effect to be studied.

4.3 Staff surveys

Survey respondents provided a fair idea of how staff within the ICU and theatres consider noise in their working environment. Of the 44 respondents, 39% disagreed with the statement “the level of noise at work does not bother me”, while 29% strongly disagreed. Together this makes up nearly 70% of all responses, indicating that all of these staff members are negatively affected by noise at least some of the time. Again, 39% of staff disagreed and 19% strongly disagreed that it would make no difference to their hearing if work was quieter, making up almost 60% of respondents. When asked if they would feel better if their workplace was less noisy, 51% agreed and 22% strongly agreed with this statement, proving over 70% of staff would like their work environments to be a bit quieter.

The statement “I cannot reduce noise in the workplace” showed almost half of staff disagreed with this, showing an internal locus of control. This will encourage staff to participate in noise-reduction efforts, some of which will be discussed in section 4.4.4. The question: “there is no route to complaining about noise” showed 46% disagreed, however 32% agreed and 19% of respondents replied they didn’t know. This variance in answers proves education about noise in the workplace is lacking and steps should be taken to ensure all staff understand this portion of health and safety. Education about harmful noise levels should also be considered, even though 51% of respondents disagreed they knew when a noise is loud enough to damage their hearing, 27% still agreed they knew these levels.

Almost 50% of respondents disagreed that their colleagues do not worry about noise. This creates an understanding that these staff members have spoken about the effects of noise in the workplace. Almost half of staff struggle carrying on a conversation due to background noise, while 41% reported they do not. The split in these answers may be due to age or hospital team, however, the distribution of survey respondents was not varied enough to analyse any significant effects of these factors. One question identified that 79% of participants either agreed or strongly agreed that noise was sometimes so loud that concentrating is difficult. This reflects a definite need for the management of noise issues in Christchurch Hospital to ensure both staff and patient safety. A minimal, but important 10% of staff agreed or strongly agreed that noise was always too loud to concentrate. Three out of the four who answered positively worked in the anaesthetic department and one was in the surgical team.

4.4 Future considerations

4.4.1 ICU

The nature of the ICU is that patients who are under their care are extremely vulnerable and need a tranquil, healthy place to recover. According to recorded noise levels and staff reports, the Christchurch Hospital ICU does not currently provide this for patients or staff.

The extension of the ICU in Christchurch Hospital provides a unique opportunity for improving the acoustics of this space. Within the new part of the ICU, building materials could be selected that absorb more sound in a sterile environment, reducing reverberation time. The addition of acoustic ceiling tiles above patient beds is also a viable option to achieving this.

Construction noise from earthquake repairs and the extension of the ICU is temporary noise which is difficult to reduce. Fife and Rappaport (1976) report that construction noise outside patients' windows slows down recovery and increases the chances of rehospitalisation. In the current study, many members of staff complained about the level of construction noise. One staff member commented on the staff survey that they have asked the men to stop so they can continue the surgical list (section 3.3). Further research should be done into preventing this temporary noise, however, financial constraints and practicality are common issues in dealing with extraneous noise.

Results from observation and preliminary noise measurements (appendix 2) show that main sources of peaks were from staff activity. With extra care and behaviour modification, some of these peaks may be able to be reduced effectively. A staff education session as tested in overseas studies (Kahn, et al, 1998; Richardson, et al, 2009) could be implemented. This guideline should consist of observed noise sources, the impact of noise for both staff and patients, overall responses from the 44 staff members

who completed the initial surveys and how to reduce this noise level within daily routines. Discussions with staff members showed that a change in staff behaviour may prove difficult without education on an internal locus of control and how they can individually reduce noise in their workplace. It is important to ensure the staff members do not think that blame is being placed, as there are multiple reasons for elevated noise levels in the ICU. However, comments from preliminary measurements, staff surveys (section 3.3) and overseas studies (Fitzgerald & O'Donnell, 2012) suggest staff speech levels are a major contributing factor.

Further noise measurement and analysis is necessary to identify more sources of noise in Christchurch Hospital. This present two-microphone study in the ICU suggests more in-depth measurements are needed to address the noise environment within the ICU directly. In future studies, more microphones would be needed in various areas of the ICU, including ward studies. Microphones should be placed at each end of the ICU, alongside the two placements in the current study. Future recordings and analysis should be completed by an investigator with acoustic knowledge to help devise a standard for noise measurement (Shahid, et al, 2014). This would provide an improved analysis of sources of noise and how to reduce noise.

Patient surveys also need to be completed to fully assess the effects of noise in the hospital. These were not able to be completed reliably in the ICU, nor with patients who had been transferred to different wards from the ICU. Marqués, et al, (2012) reported 65% of their patients considered loud speech to be the most “unbearable” noise while in hospital. In future, perhaps surveying those within different wards and taking noise level measurements of those wards would provide further information about Christchurch Hospital. In order to assess physiological effect of noise on patients, factors such as blood pressure and number of times awoken at night could be measured.

4.4.2 Surgical unit

Stress levels and an inability to concentrate in noise is an issue that has been discovered by many overseas studies (Kjellberg, et al, 1996; Stansfeld & Matheson, 2003; Way, et al, 2013) and has also been reported in staff surveys from the Christchurch surgical unit. Overseas studies have reported that orthopaedic surgeries have been the main department that needs noise reduction and this is consistent with L_{Aeq} and peak levels measured in Christchurch operating theatres.

In future it may be advantageous to monitor more surgeries, especially orthopaedics, with anaesthetic information if possible, as Ginsberg, et al (2013) reported the highest levels of noise occurred during anaesthetic induction. Various surgeons and types of operations will be necessary for noise level measurement in the future. More theatre dimensions and reverberation times should be included.

To gain a full picture of the surgical noise in Christchurch, is it recommended to monitor surgeries at Burwood Hospital too. Here full hip and knee replacements are performed, which have shown to produce much higher noise levels than ordinary review orthopaedic surgeries. Surgical tools such as hammers should be investigated for their ability to be attenuated at their source. Construction tools have been tested using lead or dead-blow hammers, which absorb some of the impact noise. Sterility is an issue with this concept in a hospital setting. Investigations could be conducted into sound-absorbing surgical tools.

In order to measure the effects of occupational noise on surgeons, hearing testing could also be performed as orthopaedic surgeons have been shown to have signs of NIHL (Kamal, 1982; Willett, 1991). It would be advantageous to measure this effect in

Christchurch Hospital staff and educate them about the dangers of noise levels in the workplace.

4.4.3 Staff surveys

Staff surveys were completed at a lower rate than expected. With an estimate of at least 200 staff, 44 completed surveys do not cover even half of the population needed. In future studies, online surveys may be easier for staff to fill out. If an email is sent to all staff, this will minimise investigator and staff time. This will save paperwork, reduce the chance of anonymity breaches (with paper copies, it is possible some staff members could see who wrote which answers), and reduce human error of miscalculating responses. Within the ICU, it would be helpful if staff could be briefed on potential noise sources, and to perhaps keep a list of loud noises they were disturbed by and the day/time of day. Bayo, et al, (1995) reported that 76% of their survey respondents thought sources of noise were from inside the hospital, mainly visitors and devices such as alarms. This should also be a question in addition to the current Christchurch Hospital survey to investigate what they consider main sources of noise. Other questions should be what types of noise were the worst subjectively (i.e alarms, loud speech), how long their shifts are approximately and whether music is a distraction. Knowing their gender may also provide some insight into response differences.

4.4.4 Noise reduction

As reported in section 1.8, stages in noise reduction have been recommended. Wyk, et al, (2012) provided a rank order for hospital noise reduction: materials, finishes and space planning; facility equipment and maintenance; hospital technology and administrative/behavioural modification. Deng, et al, (2013) reported their ICU staff voted

for acoustic treatment and reduction in alarms when improving the noise levels. In the case of Christchurch Hospital, both the ICU and theatres would benefit from improving the acoustic environment with better materials and space planning plus behaviour modification.

Chapter Five: Conclusions

Overall, noise results in the ICU exceeded the WHO recommended levels of 35dB(A) during the day and 30dB(A) overnight (Berglund, et al, 1999) for both periods by approximately 20dB(A). There were many peaks during sound level measurement which rose above 100dB(C). These levels can prevent patients from sleeping, have negative psychological and physiological effects and reduce speech intelligibility. Most overseas studies reported in section 1.5.4 found ICU L_{Aeq} levels to be between 50-60dB(A) during the day and between 45-55dB(A) at night, with peaks being above 80dB(A) or dB(C) depending on the particular study. Results from Christchurch Hospital's ICU are directly in line with overseas ICUs, with most daytime L_{Aeq} results being between 55-60dB(A) and night time 48-55dB(A). The main sources of noise within the ICU appeared to be loud speech, alarms, tools and other objects dropping/shutting.

Noise levels in surgery did not exceed Health and Safety in Employment Regulations (Department of Labour, 1995), however are still at a level that can cause stress, a loss of concentration and a potential hearing loss over years of work. The L_{Aeq} from Christchurch Hospital surgeries were similar to those reported overseas, but lower than studies in the North Island of New Zealand (Liddell, 2008; Love, 2003), thought to be the product of different types of orthopaedic surgery. The main sources of noise during Christchurch Hospital surgeries were mallets, hammers, the pneumatic drill and air suction systems.

Staff surveys indicated that 73% of staff would prefer their workplace to be less noisy and almost 60% of staff have trouble carrying on a conversation because of noise. Staff also reported that 78% of staff find concentrating difficult sometimes due to noise. Comments on these surveys indicated construction noise, loud speech, alarms and surgical tools/machines are the main disturbances. These results support noise level

measurements taken in both the ICU and theatres which can be used in conjunction for counselling, further assessment and improvement for the future, especially with the finding that noise in hospital is continuously rising (Busch-Vishniac, 2005). For both patient and staff safety and well-being, noise levels should be attenuated in the ICU and theatres. A thorough study of noise levels in different places of the ICU, various wards, more surgeries and hearing testing of staff will give investigators more useful information for improving the environment in Christchurch Hospital. Ongoing research and management in light of the current study will help ensure Christchurch Hospital is a tranquil, stress-free environment for both staff and patients.

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Appendices

Appendix 1. Human Ethics Committee Approval



HUMAN ETHICS COMMITTEE

Secretary, Lynda Griffioen
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2014/62

14 July 2014

Brian Donohue
Department of Mechanical Engineering
UNIVERSITY OF CANTERBURY

Dear Brian

The Human Ethics Committee advises that your research proposal "Noise in Christchurch Hospital" has been considered and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 11 July 2014.

Best wishes for your project.

Yours sincerely

A handwritten signature in dark ink, appearing to read 'L MacDonald'.

Lindsey MacDonald
Chair
University of Canterbury Human Ethics Committee

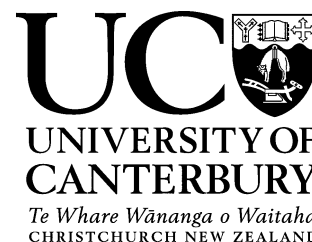
Appendix 2. Preliminary sound level measurements

LOCATION	DATE, TIME	LENGTH OF TIME, 1s measures	L _{Aeq} (dBA)	L _{AFmax} (dBA)	L _{AF90} (dBA)	L _{Cpeak} (dBC)
BED 8/NS	13/7/15, 9am, occupied	10mins	57.2	78.5	47.6	94.3 (alarm)
BED 5	13/7/15, 9:15am, beds 4,5,6,7 occupied	10mins	61.4	78.9	51.6	105.3 (bin being placed down)
CORRIDOR BY ROOM 12	13/7/15, 9:30am, 12 unoccupied	10mins	52.9	74.6	43.2	89.9 (speech)
BED 1	13/7/15, 10:00am, beds 1,2,3 unoccupied	10mins	50.8	72.0	43.8	100.2 (door slam, blood transfusion alarm)
BED 7	13/7/15, 10:30am, occupied, 2x visitors and being assessed	10mins	56.1	75.7	48.4	94.7 (trolley pushing through - metallic)
BED 8/NS	21/7/15, 3:30pm, occupied	30mins	59.6	83.2	49.5	102.8 (chairs scraping, doors shutting)
BED 5	21/7/15, 4:00pm, occupied, NS loud	30mins	59.5	80.8	51.6	99.0 (drawers shutting, loud speech)

Appendix 3. Staff survey consent and information form

Department of Mechanical Engineering

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Email brian.donohue@canterbury.ac.nz



Date August 2014

CONSENT FORM (operating theatre participants)

Survey of Noise in Hospitals

I have read and understood the information provided on the above named project. I agree to participate as an active/passive* subject and consent to publication of the results with the understanding that anonymity will be preserved. I understand that the study will capture information on noise levels only and no audio.

I understand that I may withdraw from the study without prejudice or penalty and at any time and my questionnaire together with any noise data obtained during my participation will be destroyed.

I note that the project has been reviewed and approved by the Human Ethics Committee of the University of Canterbury¹

NAME (please print)

Signature:

Date:

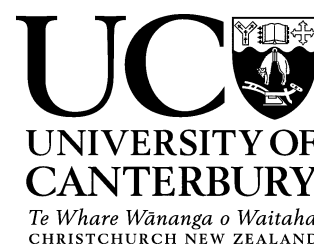
- * Active: a participant who has completed a questionnaire and has worn a dosimeter.
- * Passive: a participant who is present during the monitoring period that has completed a questionnaire but has not been subject to noise dosimetry.

¹ Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch 8140. Ph: +64 3 364 2987 extn 45588. (human-ethics@canterbury.ac.nz)

Appendix 3b. Staff survey consent and information form

Department of Mechanical Engineering

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Date August 2014

CONSENT FORM (non-theatre staff)

Survey of Noise in Hospitals

I have read and understood the information provided on the above named project. I agree to participate as a passive* subject and consent to publication of the results with the understanding that anonymity will be preserved. I understand that this study is being carried out to establish a baseline record of noise and its sources in parts of the hospital.

I understand that I may withdraw from the study without prejudice or penalty and at any time up until submission of my questionnaire. Once a questionnaire has been submitted anonymity will prevent its withdrawal.

I note that the project has been reviewed and approved by the Human Ethics Committee of the University of Canterbury²

NAME (please print)

Signature:

Date:

- * Active: a participant who has completed a questionnaire and has worn a dosimeter.
- * Passive: a participant who is present during the noise data collection period that has completed a questionnaire but has not been subject to individual noise dosimetry.

² Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch 8140. Ph: +64 3 364 2987 extn 45588. (human-ethics@canterbury.ac.nz)

Appendix 3c. Staff survey consent and information form

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INFORMATION – Noise in the hospital survey (staff)

As a member of the staff of Christchurch Hospital you are invited to participate in a study that aims to define the acoustic environment in the hospital. Your participation does not require you to do anything other than your normal duties but because you may or may not be present when noise data collection is being used we will ask for your consent. A small number of theatre staff will be asked if they would participate in noise dose monitoring, which requires the wearing of a dosimeter and microphone during their normal activities. All participating staff members are requested to complete the attached survey questionnaire place it in the envelope provided and deposit it in a drop box at a nurse's station. Your participation will help us to improve the acoustical environment at Christchurch Hospital.

The incidence of high noise levels is common in hospitals around the world. The Canterbury District Health Board seeks to identify the sources and characters of noise that causes disturbances to staff and patients in the Christchurch Hospital, with a view to finding ways to reduce or eliminate them. The research team is also interested in finding out how staff perception of noise correlates with actual measured noise levels. The project involves monitoring noise levels in selected wards, at nurse stations, and in theatres in the hospital, and in some cases the wearing of a noise dosimeter to assess daily exposure. The dosimeter is a lightweight instrument that measures the wearer's daily exposure to noise – it does not record audio, merely the sound level at increments of time. Staff who agree to the wearing of a dosimeter will not be identified by name in any reporting – the objective is to find out what cumulative noise level the staff is exposed to during their “normal” theatre activity. Dosimetry will be offered for a theatre nurse, a surgeon and/or consultant, and an anaesthetist. For some monitoring periods, theatre activity will be physically noted by the student so that we can correlate noise sources with noise levels – again, no audio data will be recorded. The intention is to gather evidence based noise data that will be used for planning, education and development of mitigation measures. The data collected will address local conditions in Christchurch Hospital but may also contribute in the formation of a national study. If the study is extended to other hospital groups your continued anonymity is assured.

By returning a consent form and a completed survey you indicate your willingness to participate in the study. However, you have the right to withdraw from participation at any time, without prejudice or penalty. If you have any questions during this study please feel free to contact one of the investigators listed below. Thank you for your time, consideration and contribution to our study.

Appendix 3d. Staff survey consent and information form

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch 8140. (human-ethics@canterbury.ac.nz).

The research is being conducted by:

Principal investigator:

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If you have any concerns about participation in the project please discuss with the principal investigator.

Appendix 4. Staff survey questionnaire.

University of Canterbury's Hospital Noise Survey questionnaire (staff)

1 My age is:

- ☐ Under 20 ☐ 21 - 30 ☐ 31-40 ☐ 41-50 ☐ Over 50

2 I have worked in the health sector in New Zealand for:

- ☐ Less than 1 year ☐ 1 to 3 years ☐ 3 to 6 years ☐ 6 to 10 years ☐ More than 10 years

3 The level of noise at work does not bother me:

- ☐ Strongly agree ☐ agree ☐ disagree ☐ Strongly disagree ☐ Don't know

4 It would make no difference to my hearing if it was quieter at work:

- ☐ Strongly agree ☐ agree ☐ disagree ☐ Strongly disagree ☐ Don't know

5 I would feel better if my workplace was less noisy:

- ☐ Strongly agree ☐ agree ☐ disagree ☐ Strongly disagree ☐ Don't know

6 My friends or family think I have a hearing problem:

- ☐ Strongly agree ☐ agree ☐ disagree ☐ Strongly disagree ☐ Don't know

7 I cannot reduce noise in the workplace:

- ☐ Strongly agree ☐ agree ☐ disagree ☐ Strongly disagree ☐ Don't know

8 There is no route to making complaints about workplace noise:

- ☐ Strongly agree ☐ agree ☐ disagree ☐ Strongly disagree ☐ Don't know

9 I know when a noise is loud enough to damage my hearing:

- ☐ Strongly agree ☐ agree ☐ disagree ☐ Strongly disagree ☐ Don't know

10 Noise only affects hearing in people with sensitive ears:

- ☐ Strongly agree ☐ agree ☐ disagree ☐ Strongly disagree ☐ Don't know

11 My work colleagues do not worry about noise:

- ☐ Strongly agree ☐ agree ☐ disagree ☐ Strongly disagree ☐ Don't know

12 I have trouble carrying on a conversation because of background noise:

- ☐ Strongly agree ☐ agree ☐ disagree ☐ Strongly disagree ☐ Don't know

13 Noise is sometimes so loud I find it hard to concentrate:

- ☐ Strongly agree ☐ agree ☐ disagree ☐ Strongly disagree ☐ Don't know

Appendix 4b. Staff survey questionnaire.

14 Noise is always so loud I find it hard to concentrate:

☐ Strongly agree ☐ agree ☐ disagree ☐ Strongly disagree ☐ Don't know

15 I am a member of:

☐ A ward nursing team ☐ A clinical team ☐ A surgical team ☐ An anaesthetics team

Add Comments about the survey if you wish

Appendix 5. Patient survey questionnaire and information sheet

Patient discharge survey on noise - stay in Christchurch Hospital

*Please answer the following questions where you can by marking the appropriate box(es) or filling in the blanks. Then please return the completed survey, in the envelope provided, to the nursing staff or post in the drop-box at the nurse's station as you leave.
Thank you for your participation.*

Gender: Male ☐ Female ☐

Age: 19-25 26-30 31-35 36-40 41-45 46-50 51-55 56-60 61-65 66-70 71-75 76+

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

1 Do you (the patient) have any known hearing impairment? Yes ☐ No ☐

2a At **NIGHT**, how often were you awakened by **noises** during your hospital stay?

Never ☐ Rarely ☐ Sometimes ☐ Often ☐

2b How annoyed were you at being disturbed?

Did not wake ☐ Not at all ☐ Slightly ☐ Moderately ☐ Extremely ☐

3a During the **DAY**, how often was your rest disturbed by **noises** during your hospital stay?

Never ☐ Rarely ☐ Sometimes ☐ Often ☐

3b How annoyed were you at being disturbed?

Did not wake ☐ Not at all ☐ Slightly ☐ Moderately ☐ Extremely ☐

4 Please rank the sources of noise that disturbed you during your hospital stay, using a scale of 1 to 5, with 1 being the most bothersome.

Medical equipment **in** your room ☐ Medical equipment **outside** your room ☐

Alarms **in** your room ☐ Alarms **outside** your room ☐

Others talking **in** your room ☐ Others talking **outside** your room ☐

Trolley(s) in the hallway ☐ Office equipment **outside** your room ☐

TV's ☐ Other entertainment devices ☐ heating and ventilation system ☐

Other (please describe): _____ ☐

5a Did you ever have a hard time hearing or understanding what the medical staff was saying to you because of noise? Yes ☐ No ☐

5b If yes, how often?

Never ☐ Rarely ☐ Sometimes ☐ Often ☐

6a Were you able to hear other patients, guests, or staff discussing private information that did not concern you? Yes ☐ No ☐

6b If yes, how often?

Never ☐ Rarely ☐ Sometimes ☐ Often ☐

Appendix 5b. Patient survey questionnaire and information sheet

7 Would you describe yourself as being sensitive to noise? Yes ☐ No ☐

8 Please make any additional comments, regarding noise during your stay in hospital, in the space below:

Comments:

[This questionnaire has been adopted from: Wiese, C.H. (2010). *Investigation of patient perception of hospital noise and sound level measurements: before, during, and after renovations of a hospital wing*. University of Nebraska – Lincoln, MSc thesis Architectural Engineering].

Appendix 5c. Patient survey questionnaire and information sheet

Department of Mechanical Engineering

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QUESTIONNAIRE – Noise in the hospital survey (patients)

You are invited to participate in a research project that is studying noise in the hospital. The aims of the project are to determine the level, character, and severity of noise sources in the hospital environment as part of a program to reduce or eliminate noise. Patients often complain about noise they experience during their stay in hospital and the Canterbury District Health Board seeks to identify the sources and characteristics of the noises that cause disturbance in Christchurch Hospital, with a view to finding ways to reduce or eliminate them. They are also interested in finding out how patient perception of noise correlates with actual measured noise levels.

As a patient who is over 18 years old and has stayed at least one night in the Christchurch Hospital we request that you complete the attached survey, place it in the envelope provided and hand it in to a nurse or post into a drop box at the nurse's station before you leave the hospital. Your participation will help us to improve the comfort of patients during future stays at Christchurch Hospital.

By returning the completed questionnaire you indicate your willingness and consent to participate in the study. However, you have the right to withdraw from participation at any time without prejudice, up until you hand the questionnaire to a staff member or post it into a drop box. This is because the questionnaire is anonymous and so it cannot be retrieved once it is handed in and is mixed with other submissions. If you have any questions regarding this study please feel free to contact the principal investigator. Thank you for your time and consideration.

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

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Appendix 6. Fletcher-Munson equal loudness contours (Fletcher & Munson, 1933).

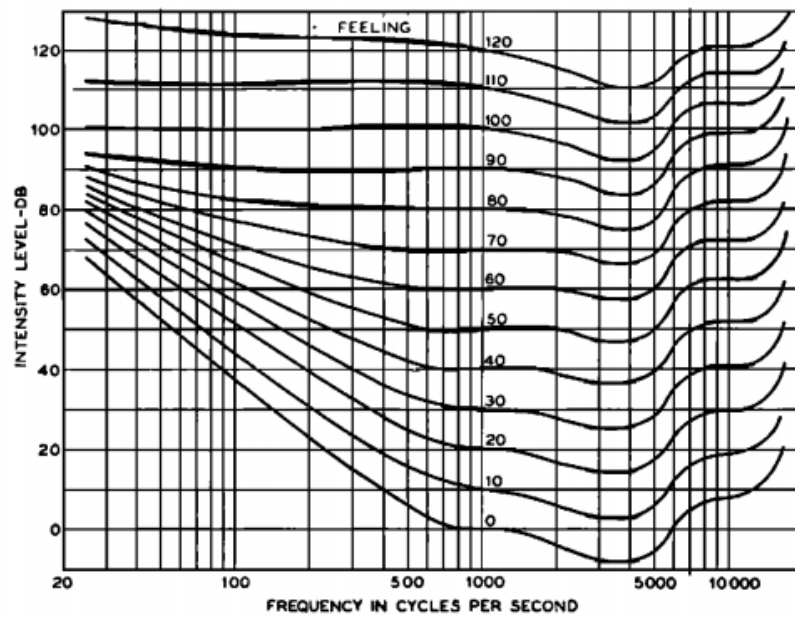


FIG. 4. Loudness level contours.

Appendix 7. Busch-Vishniac rising noise levels (Busch-Vischiac, et al, 2005).

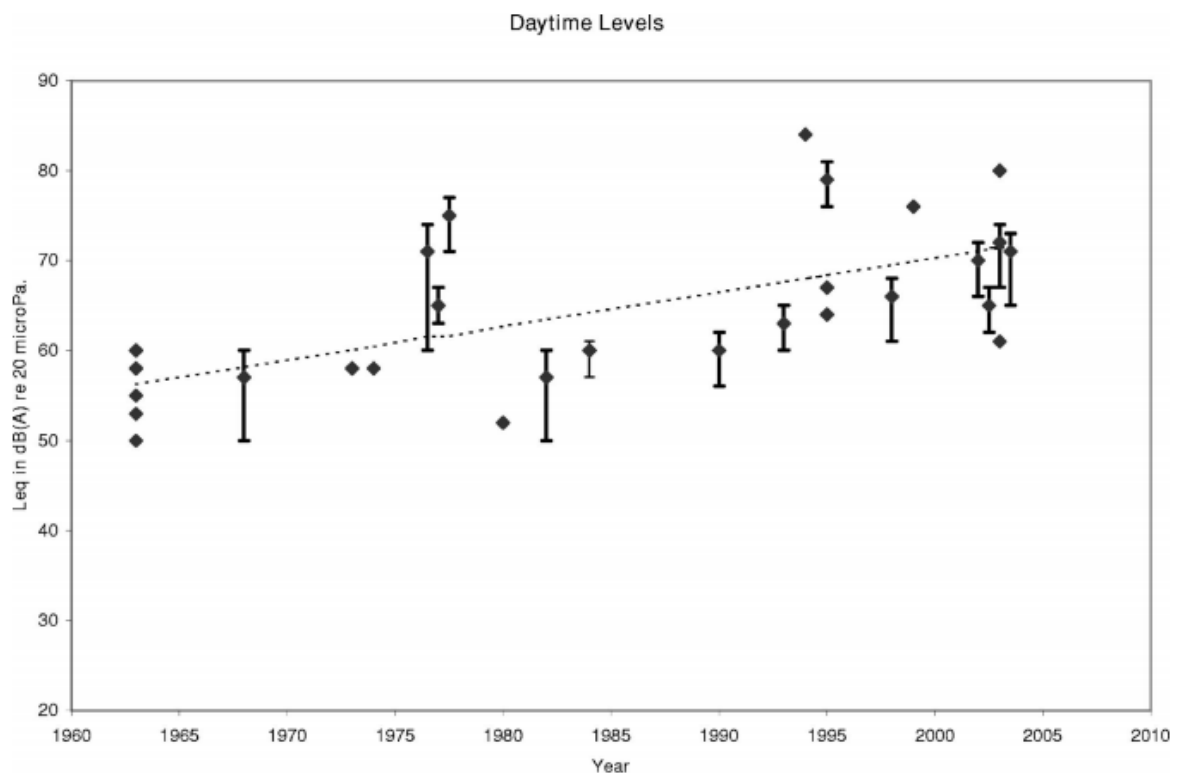
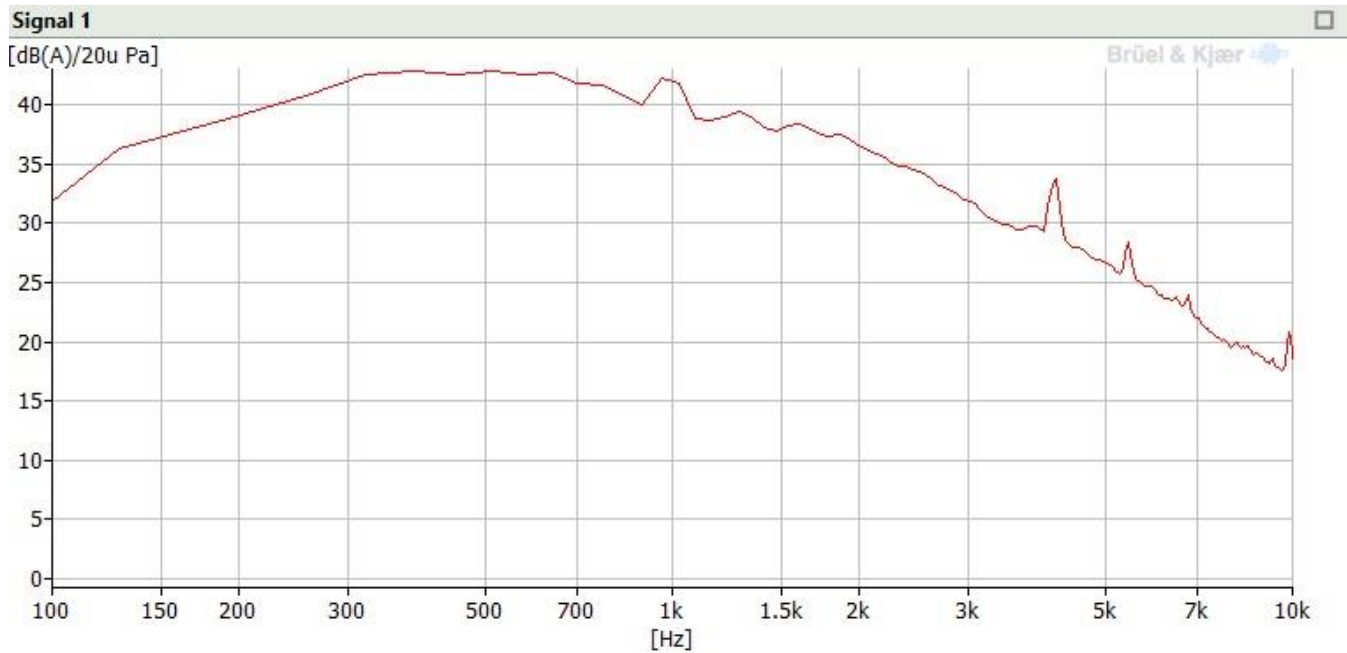
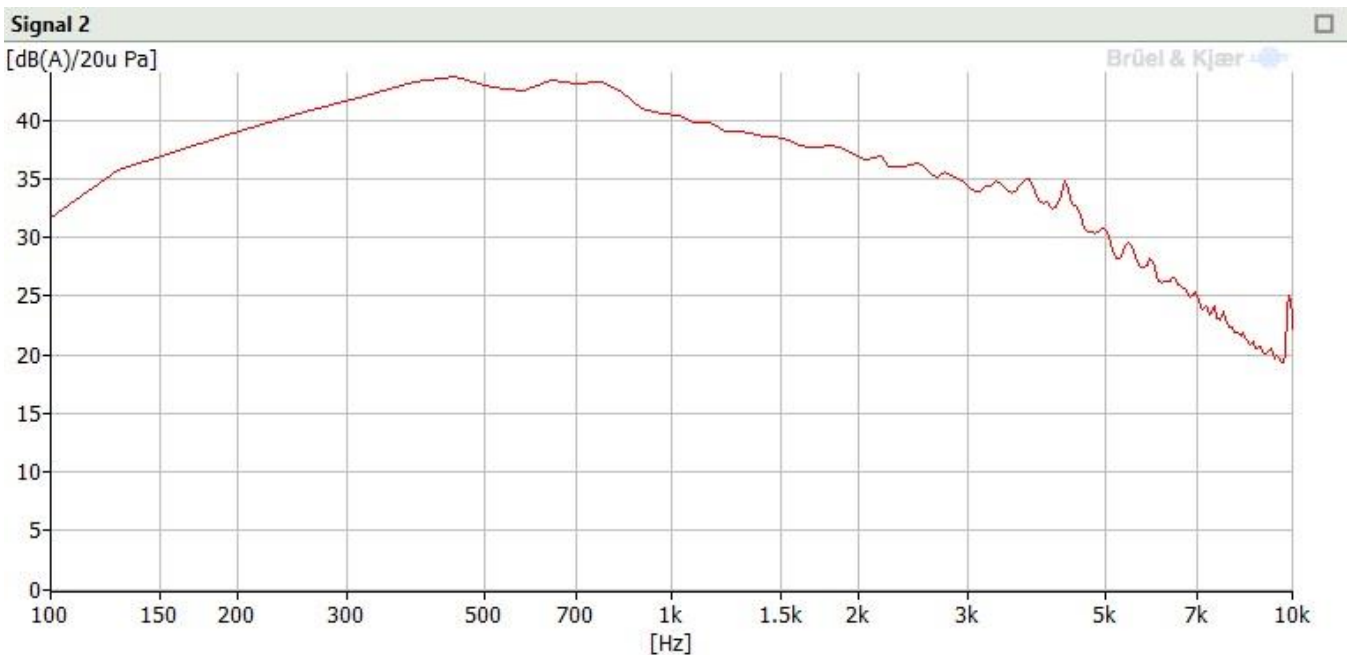


FIG. 1. A-weighted equivalent sound pressure levels measured in hospitals during daytime hours as a function of the year of study publication. Error bars indicate that data were given as a range spanned by the error bar. In these cases, the data point is shown as the logarithmic average of the range extreme values.

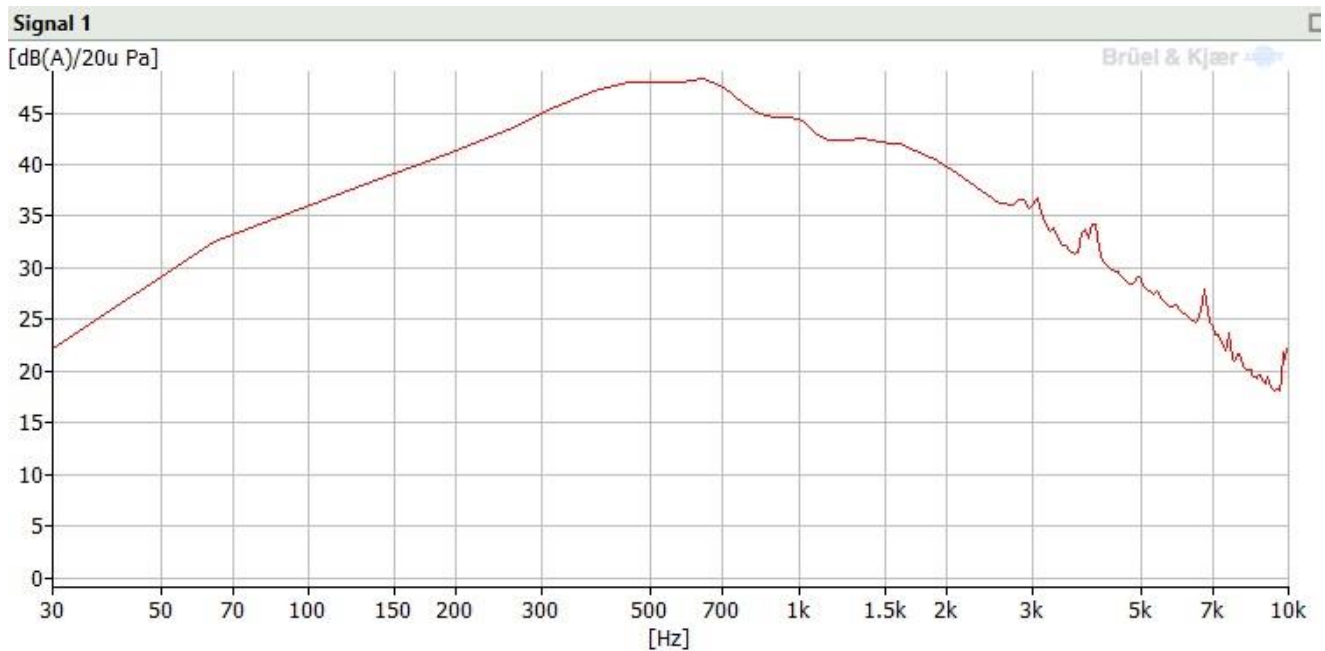
Appendix 8a. Spectral analysis of noise levels on Thursday morning, including a high number of peaks with microphone 1.



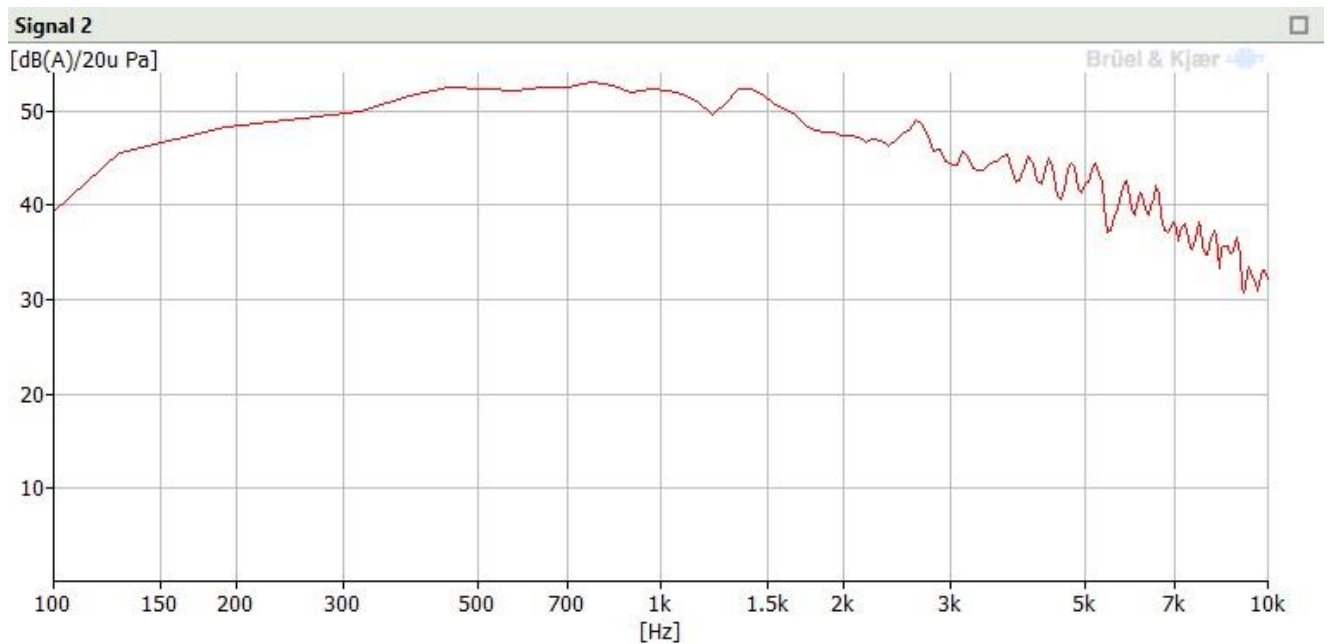
Appendix 8b. Spectral analysis of noise levels on Thursday morning, including a high number of peaks with microphone 2.



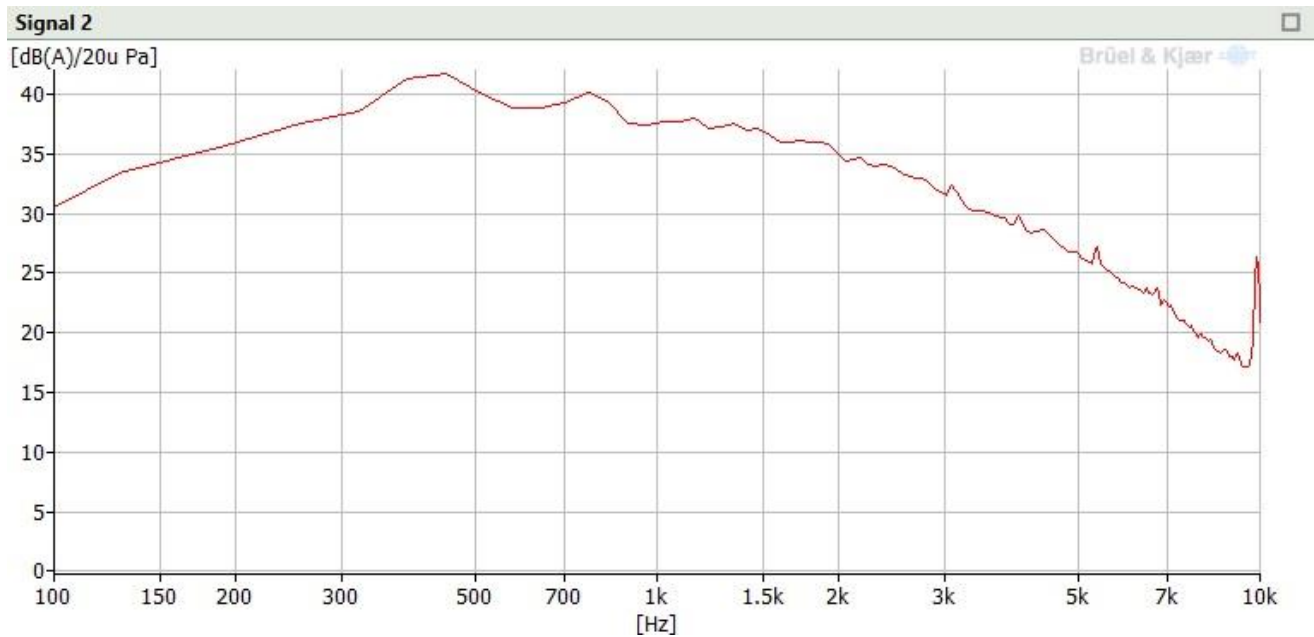
Appendix 8c. Spectral analysis of noise levels on Monday morning, including a high number of peaks with microphone 1.



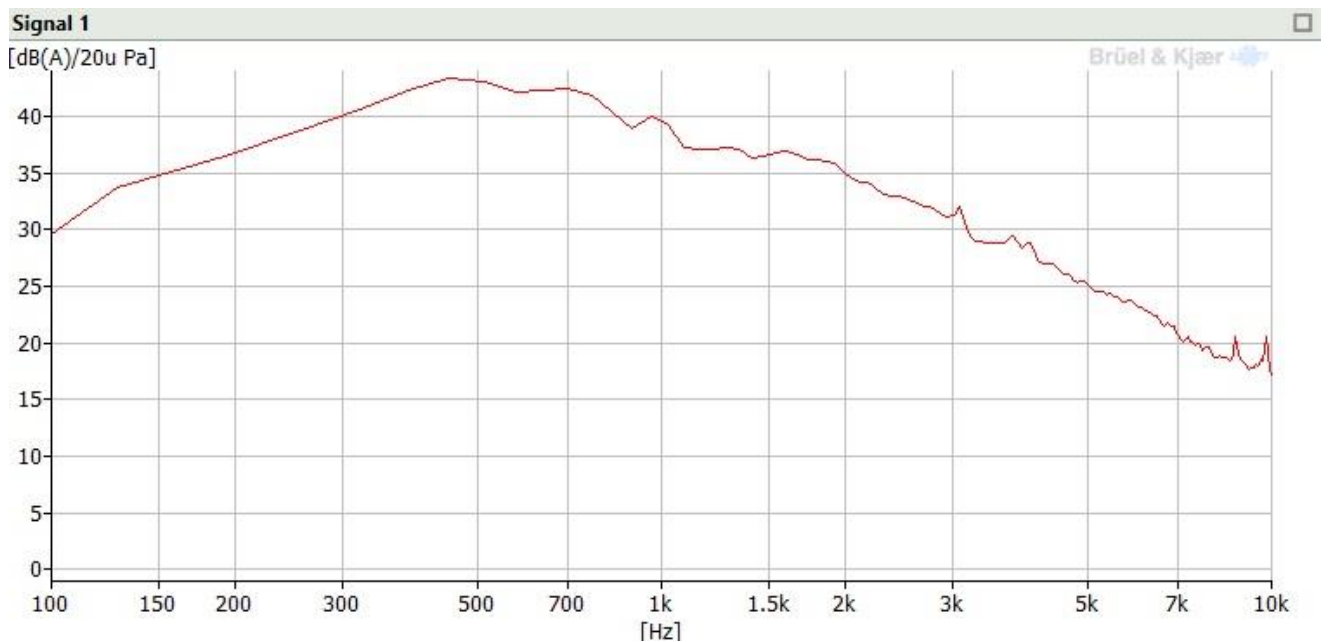
Appendix 8d. Spectral analysis of noise levels on Saturday night, including a high number of peaks, one at 135dB(C) with microphone 2.



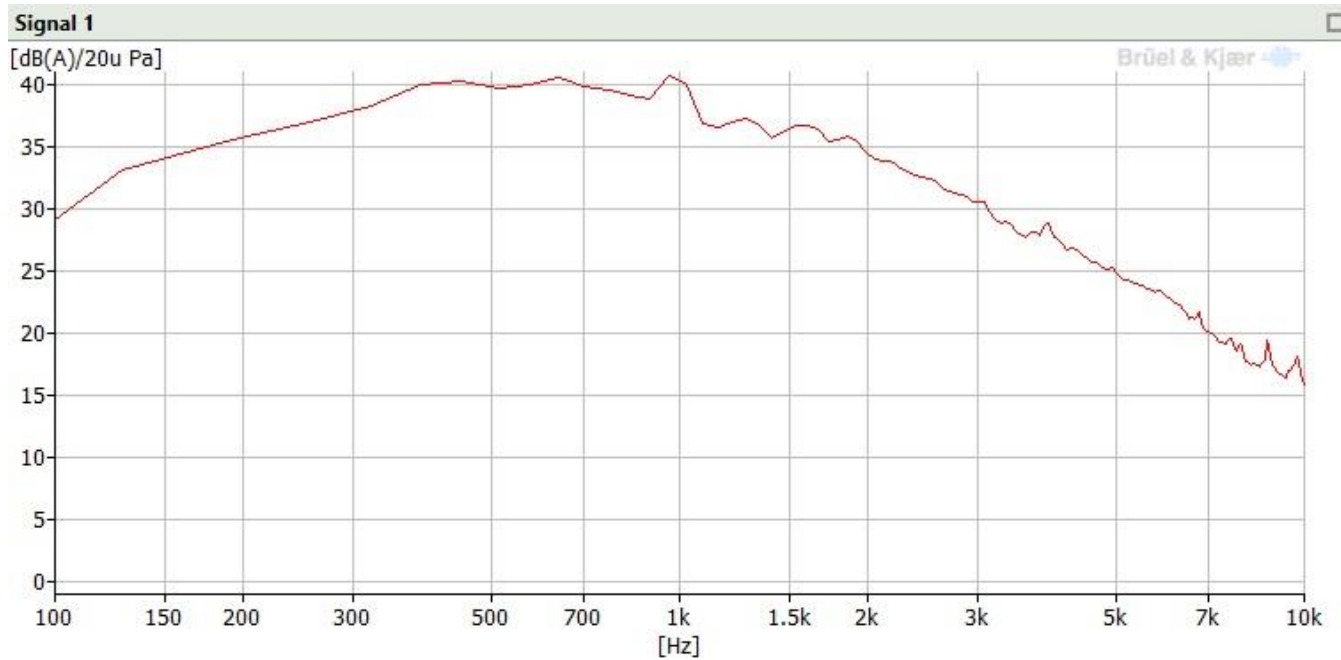
Appendix 8e. Spectral analysis of noise levels on Thursday early morning, including a low number of peaks with microphone 2.



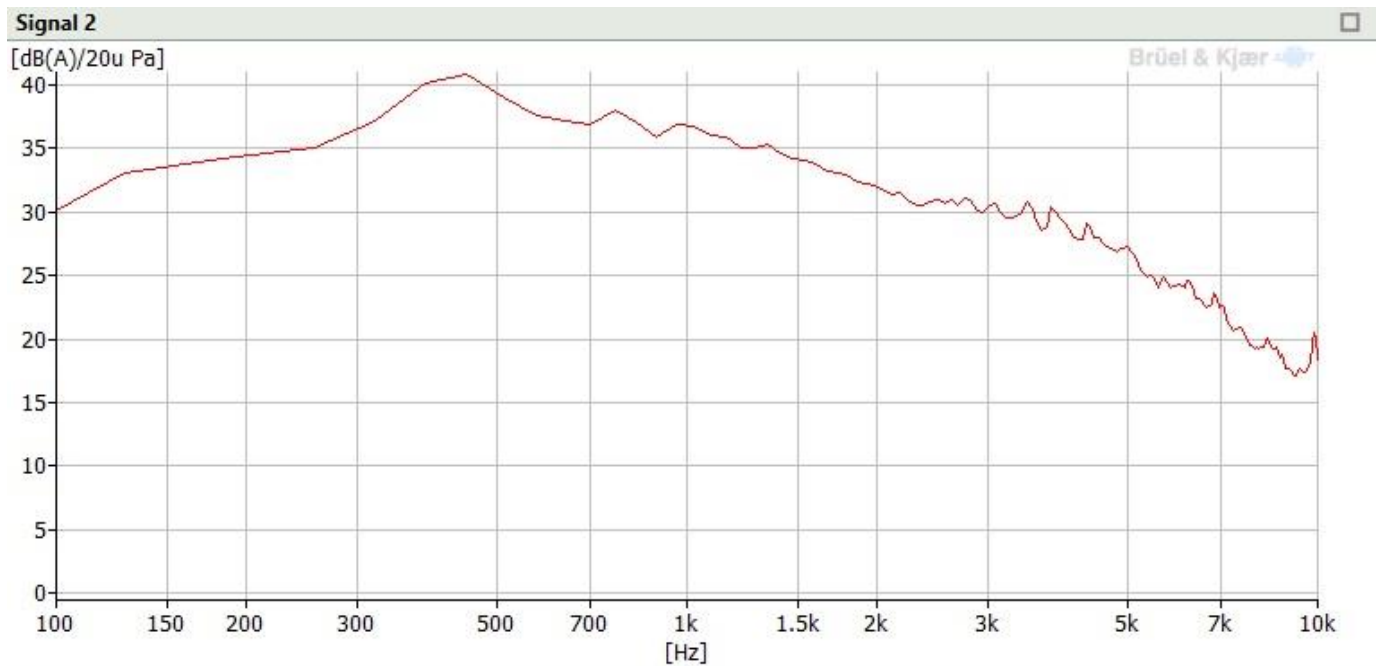
Appendix 8f. Spectral analysis of noise levels on Monday night, including a low number of peaks with microphone 1.



Appendix 8g. Spectral analysis of noise levels late Monday night, including a low number of peaks with microphone 1.

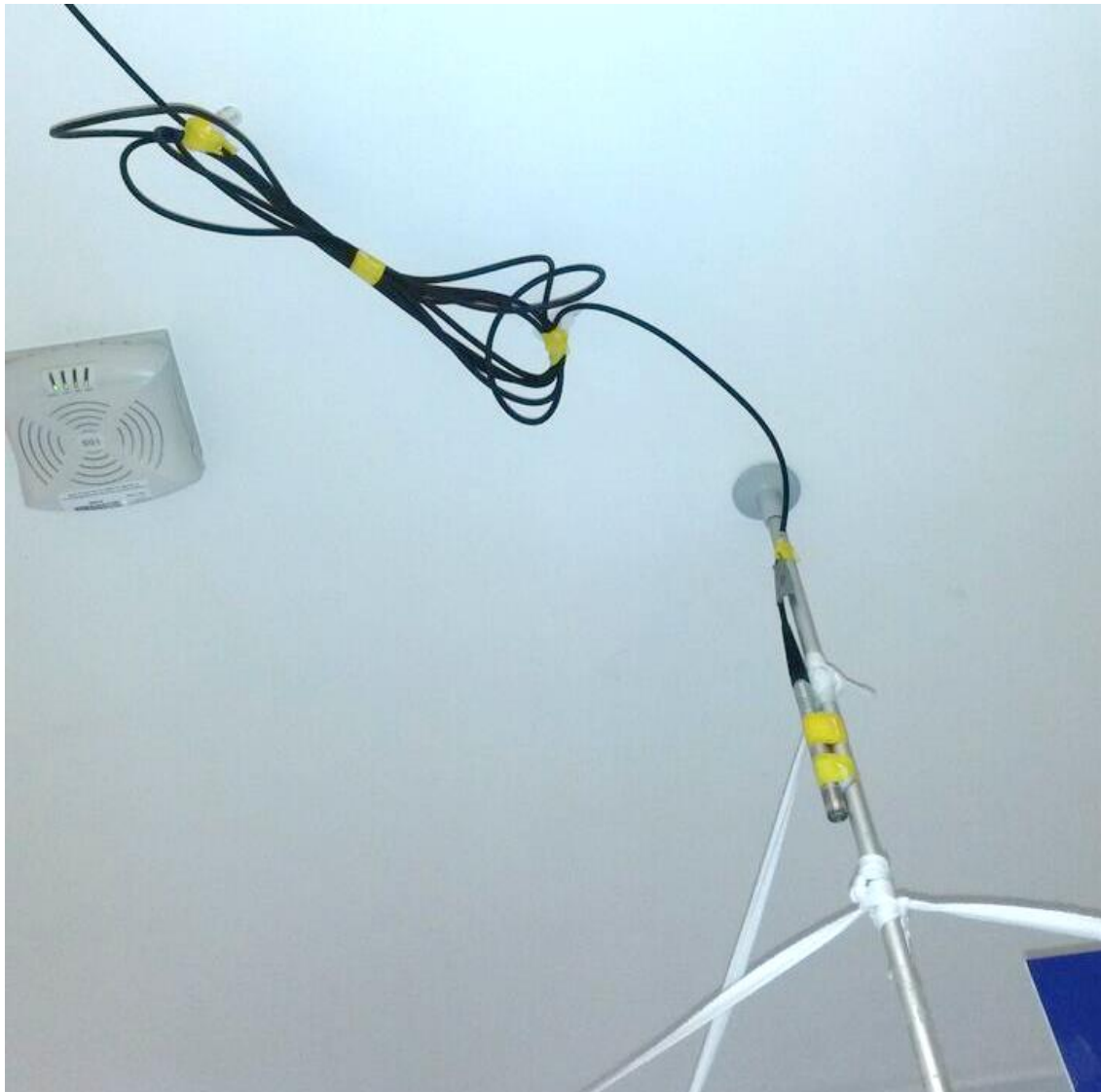


Appendix 8h. Spectral analysis of noise levels on Wednesday early morning, including a low number of peaks with microphone 2.



Appendix 9. Microphone placements in the ICU

Appendix 9a. Microphone one placement (intersection of beds seven and eight).

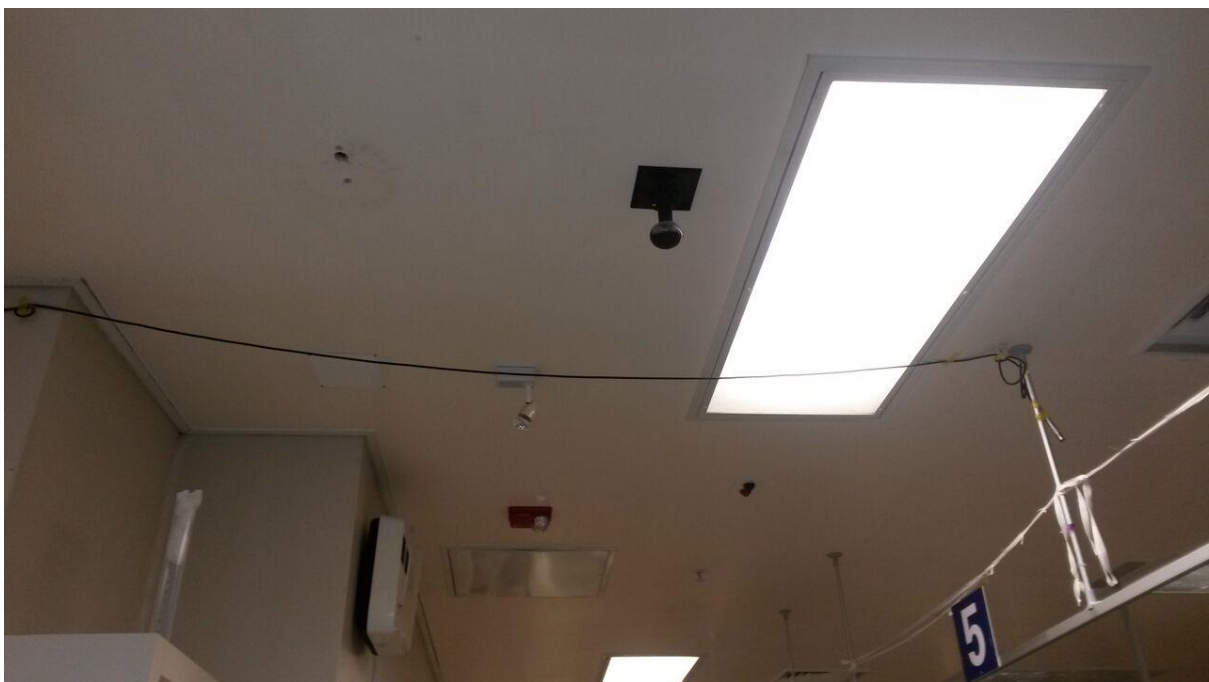


NB: Photo taken during test set-up. Microphone was moved out further from metal pole prior to sound level measurement.

Appendix 9b. Microphone cables running along the side of administration/nursing station.



Appendix 9c. Microphone two cables running along the ceiling to bed five.



Appendix 9d. Microphone two placement above bed five.

